



NATIONAL STEEL AND SHIPBUILDING COMPANY

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TO
STANDARDIZE EQUIPMENT
AND SYSTEM
INSTALLATIONS

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

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6 MANUFACTURING AND INSTALLATION TECHNIQUES

OVERVIEW

This section investigated the candidate attachment techniques and manufacturing processes that would significantly reduce manufacturing and installation time. Significant savings are possible for H, M & E equipment and system installations by shifting manufacturing work to the shop and by designing the ship systems for easy installation during ship assembly. The combination of these two factors will greatly reduce the overall time of construction from keel laying to ship delivery.

Current shipbuilding practice is governed by obsolete and inefficient technologies that result in a disproportionately large amount of labor man-hours being spent aboard the ship assemblies and erection units rather than in the more efficient shop environment. It is generally recognized that shop work is more efficient than shipboard work. Modular construction is touted as a modern technique for reducing ship construction costs. While hull structure costs have been somewhat reduced by modular construction techniques, labor hours required to outfit the subassemblies and erection units remain very high. Accordingly, the installation man hours of H,M&E equipment and distributive systems aboard subassemblies, assemblies and erection units is approximately ten (10) times the man hours spent in the shop.

The technologies, materials, devices, methods, processes and techniques used today for the installation of individual or combined systems or equipments are based on old-fashioned ship design approaches. The typical approach used in shipyards responsible for the design and construction of our modern US surface combatants and commercial ships is to use technologies, methods, processes and standards from previous ship designs. Designers are instructed by in house office procedures to use examples from previous designs as guidance for new designs. The US surface combatant/commercial shipbuilding community is reluctant to change because the practice appears to work and the status quo is maintained. While some change has occurred, the process is evolutionary rather than revolutionary. In order to make US surface ships more affordable, a radical change in the technologies to install H, M&E equipment and systems is necessary. The "devil is in the details," thus revolutionary changes in the technologies, materials, devices, methods, processes and techniques used to install H, M&E equipments and systems are necessary if we are to make US combatants and commercial ships more affordable.

APPROACH

In order to achieve these dramatic cost savings to make US surface ships more affordable, an effective strategy to revolutionize HM&E technologies must be developed in order to change the design and construction practices for US Navy surface ships. These important strategies are offered for review:

1. Identify revolutionary technologies for installing H, M & E individual or combined systems or equipments that will substantially reduce both the time and cost for the overall design, construction and delivery of ships;
2. Explore development of revolutionary techniques, methods and standards that will significantly reduce on-block H, M & E individual or combined systems or equipment installation time and costs by shifting work from the ship to the shop;
3. Explore development of revolutionary technologies that will accelerate ship construction with a dynamic build and outfit strategy to radically reduce the keel laying to ship delivery time.
4. Perform exploratory investigations to include analytical and experimental development of the revolutionary H, M & E outfit installation techniques, methods and standards to include strength, fatigue and dynamic loading assessments to satisfy both commercial vessels and U.S. Navy performance requirements.
5. Develop guidance and standards for rapid installation of individual or combined systems or equipments.

These strategies are essential to conducting an exploratory development of HM&E technologies that can revolutionize US Navy surface ship design and construction to provide more affordable ships. Important considerations in carrying out these considerations are outlined as follows:

TECHNOLOGIES TO INSTALL SYSTEMS AND OUTFIT TO REDUCE TIME AND COSTS

The cost of H, M & E equipment, outfit and distributive system installations, i.e., piping, electrical and HVAC systems is extremely high per ton in comparison to the cost of fabrication and erection of basic hull steel, because engineering and design procedures as well as fabrication and installation procedures are labor intensive. The present technology for installing H, M & E equipment foundations, equipment and distributive systems affects the time required to complete on-block assembly, therefore the technology affects the critical path for ship construction. There has been little effort expended to reduce the labor and high cost of foundations, their installation and H, M & E system installations.

The development of new and innovative standards for H, M & E foundations and systems installations can reduce the cost of their manufacture and can significantly reduce the time required for installation that is on the critical path for overall ship construction. Reduction in on-block assembly time would reduce the overall construction time from keel laying to delivery. Cost and time parameters that can be affected by standards development include:

- Design and engineering labor,
- Manufacturing labor, for H, M & E systems installations,
- Shipyard handling labor and overhead,
- Installation of H, M & E equipment and systems labor,
- Reduction in sub-assembly construction time,
- More rapid ship assembly to reduce ship delivery time.

The use of new and innovative standards for HM&E equipment and system installations will significantly improve productivity, quality and customer satisfaction and will reduce the cost and overall construction time for ships. These standards developed to suit the performance requirements for U.S. Navy vessels will substantially reduce their acquisition cost and will enable earlier delivery of the vessels.

TECHNOLOGIES TO REDUCE ON-BLOCK CONSTRUCTION TIME BY SHIFTING WORK FROM THE SHIP TO THE SHOP

New techniques, methods and standards for installing H, M & E equipment and systems can revolutionize ship assembly practice to achieve significant reduction in on-block construction time by shifting work performed from the ship to the shop.

Ship hull construction employing modular assembly and erection techniques has altered ship construction practice and has achieved significant cost savings compared to old fashioned techniques used when ship hulls were constructed piece by piece on the building ways. However, the traditional techniques and methods to outfit ships, i.e., fabrication of foundations, installation of equipment, and both the fabrication and installation of distributive systems and outfit items, have not been substantially improved to reduce the cost of ships. An extraordinary amount of time, perhaps as much as 10 to 1, is spent by labor aboard ship, (on-block assembly) rather than in the shop. Additional time spent in the shop manufacturing improved techniques, methods and standards to facilitate installation of H, M & E equipment, systems and outfit aboard ship will significantly reduce on-block labor.

The old fashioned techniques employed for outfitting on-block are reflected in long construction times and greater shipyard man-hours for both direct and indirect labor and other time dependent costs of construction. The non value-added labor

for designing custom parts, material take-off, handling, storing, tracking, retrieving and transporting parts to the job site aboard ship, tacking, welding, cleaning and painting of parts are not normally reflected in the current job cost accounting that is traceable to the part, thus it is difficult to quantify alternative methods in terms of shipbuilding time and cost reduction.

New techniques, methods and standards that will permit shifting on-block H, M & E work from the ship to the shop will result in a significant reduction of on-block time and costs while increasing shop work a small amount in comparison. The development of standard techniques, and methods for installation also will reduce costs for fabrication of H, M & E system components.

TECHNOLOGIES THAT WILL ACCELERATE SHIP CONSTRUCTION WITH A RAPID OUTFIT AND BUILD STRATEGY

New technologies for materials, fabrication techniques and standard designs for equipment and systems that permit easy and fast installation of H, M & E equipment and systems will revolutionize and accelerate the ship assembly process. New techniques for H, M & E foundations and system installations will permit easy and rapid attachment of both large and small equipments (pumps, motors, controllers, etc.) and piping, cabling and HVAC systems, etc. to the ship hull structure with minimum labor content. The installation process will be more analogous to the automobile assembly process using quick mechanical installations rather than the heavy and time consuming welding processes used presently to install foundations and systems. The "Family of Foundations" illustration, shows foundation designs that have been developed to facilitate simplified attachment methods.

FAMILY OF FOUNDATIONS

The development of revolutionary standards for H, M & E equipment and systems installations that will permit rapid modular assembly will facilitate the construction of the hull modules by reducing the labor time and cost in both the "Hot" pre-outfit and "Cold" outfit phases of construction. This exploratory research and development effort will focus on the development of techniques, methods and standards that will facilitate the shifting of H, M & E outfit of foundations and systems installations from the labor intensive "Hot" pre-outfit construction practice to the considerably more efficient "Cold" outfit assembly line practice. See Figure 6-1.

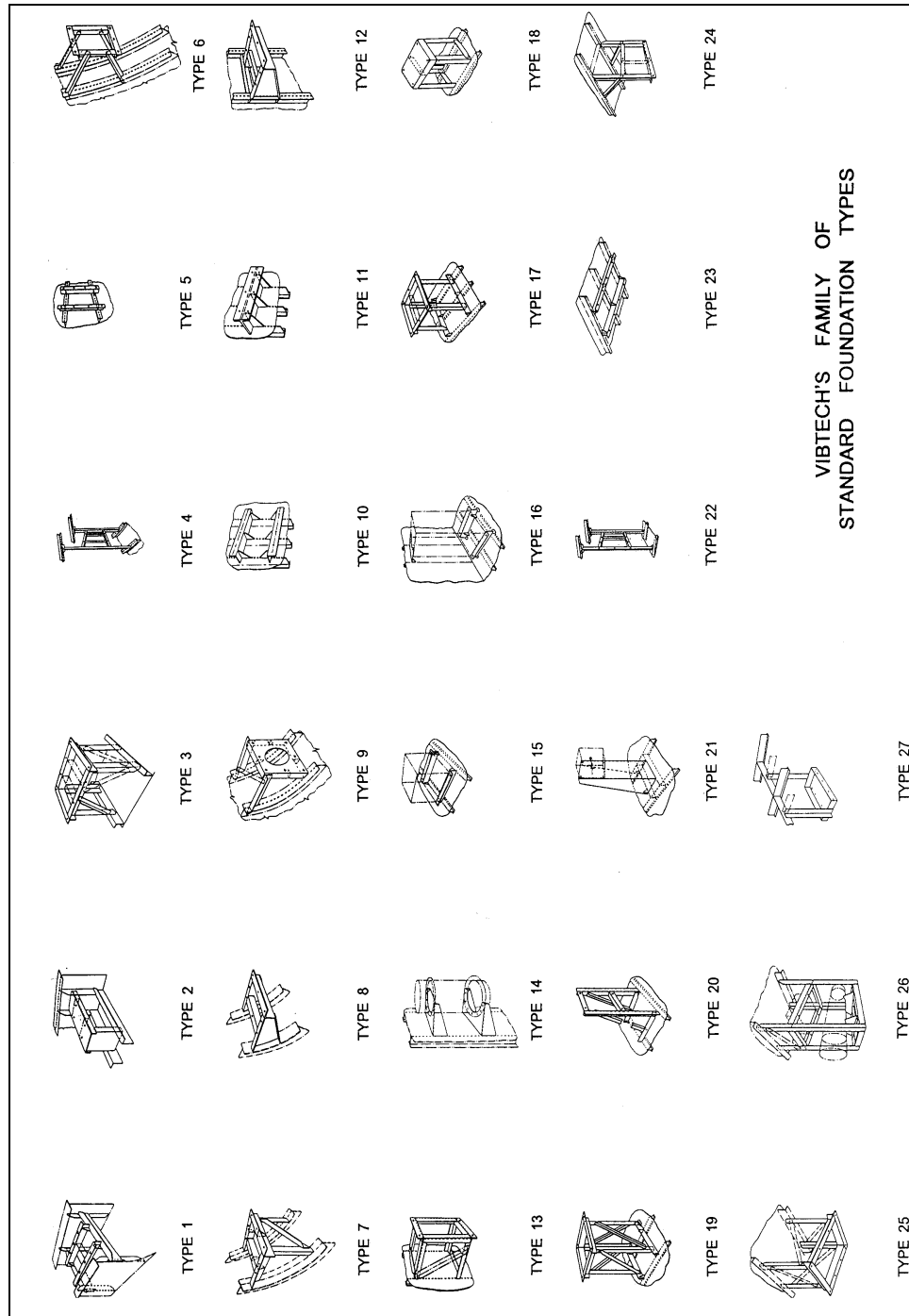


Figure 6-1 — Family of Foundations

The new techniques, methods and standards developed to suit both shop work and simplified outfit will integrate nicely with Simulation Based Design (SBD) and concurrent engineering to reduce overall engineering design time. The development of H, M&E systems installations to support a more competitive build strategy using the revolutionary H, M&E standards will achieve significant reduction in ship construction time and costs.

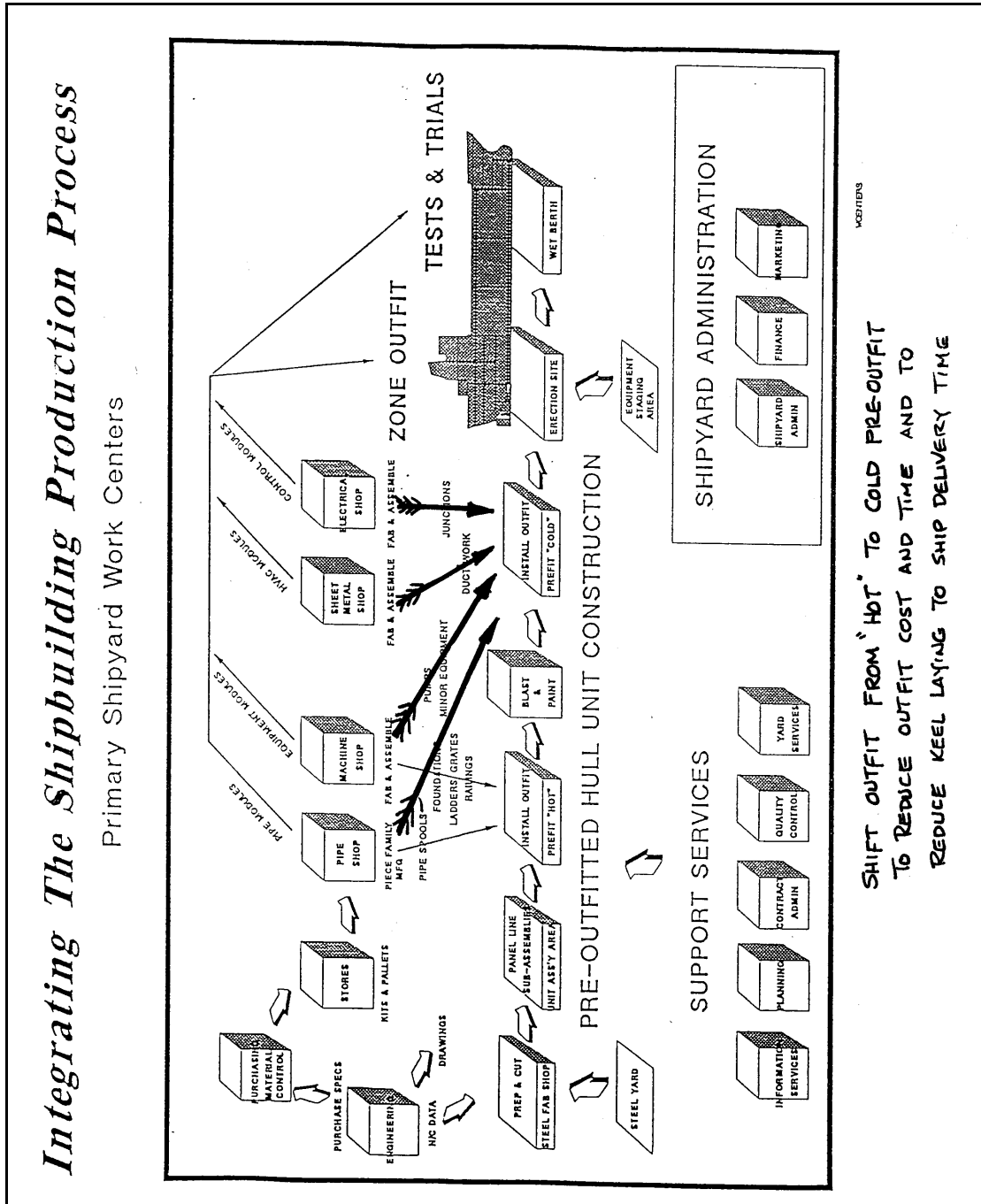


Figure 6-2 — Shipbuilding Production Process

ANALYTICAL AND EXPERIMENTAL INVESTIGATIONS REQUIRED TO VALIDATE RAPID H, M&E OUTFIT AND BUILD STRATEGY

In order to provide more affordable ships through the development of revolutionary HM&E technology concepts, it is essential to perform research and development of these revolutionary concepts and their arrangements in order to establish their validity and acceptability for use in both U.S. Navy and commercial applications. It is proposed that appropriate strength, fatigue, shock, noise and vibration investigations be made to identify all performance requirements, analysis be made and experimental testing be conducted on a selected set of representative H, M & E equipments and distributive system installations to validate the performance capability of new revolutionary techniques, methods and standards proven to be cost effective. It is anticipated that this effort will demonstrate the validity of the development of new H, M & E revolutionary concepts for outfit and build strategy and will result in a revolutionary approach to ship design and construction that will achieve the affordability goals of this solicitation, the U.S. Navy and commercial interests.

GUIDANCE AND STANDARDS FOR RAPID OUTFIT AND BUILD STRATEGY

These investigations should result in the development of guidance and standards to support design development and construction for both US Navy surface ships and commercial vessels. These new techniques, methods and standards will facilitate a new outfit strategy that will permit shifting of labor intensive and high cost work performed in the ship to a more efficient work environment in the shop. This new technology will also permit the development of a change in the build strategy for ships that will reduce the time required to outfit ships in both the "Hot" pre-outfit stage and the "Cold" outfit stage of construction.

ADAPT MECHANICAL CONNECTIONS TO FACILITATE OUTFITTING STRATEGIES

The approach we have taken is to develop candidate details to install Hull, Mechanical, and Electrical system components for individual and/or combined systems and equipments. See Figure 6-2 for candidate equipment installation detail concepts.

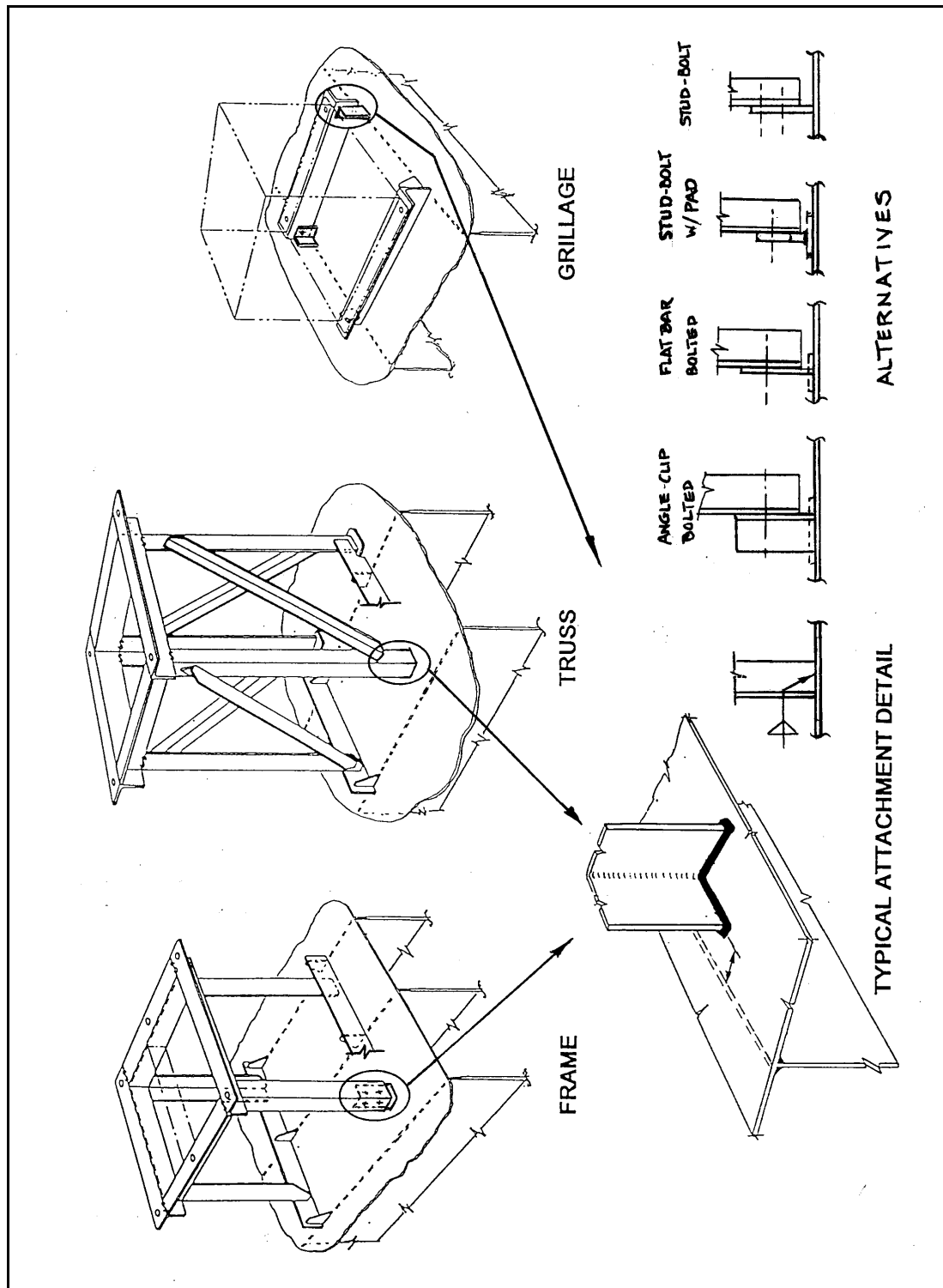


Figure 6-1 — Typical Attachment Detail Alternatives

DEVELOP MECHANICAL SYSTEM ATTACHMENT FOR SPACE FRAME LATTICE AND OTHER SYSTEM OUTFIT PACKAGING TECHNIQUES

We have developed an approach to outfitting methods using panels, gridwork, space-frame lattice works, packages and outfit modules to support an advanced outfitting strategy using mechanical attachment techniques. These methods and techniques should facilitate blast and paint, fitting insulation and final installation of individual or combined system and/or equipment installations. See Figure 6-3.

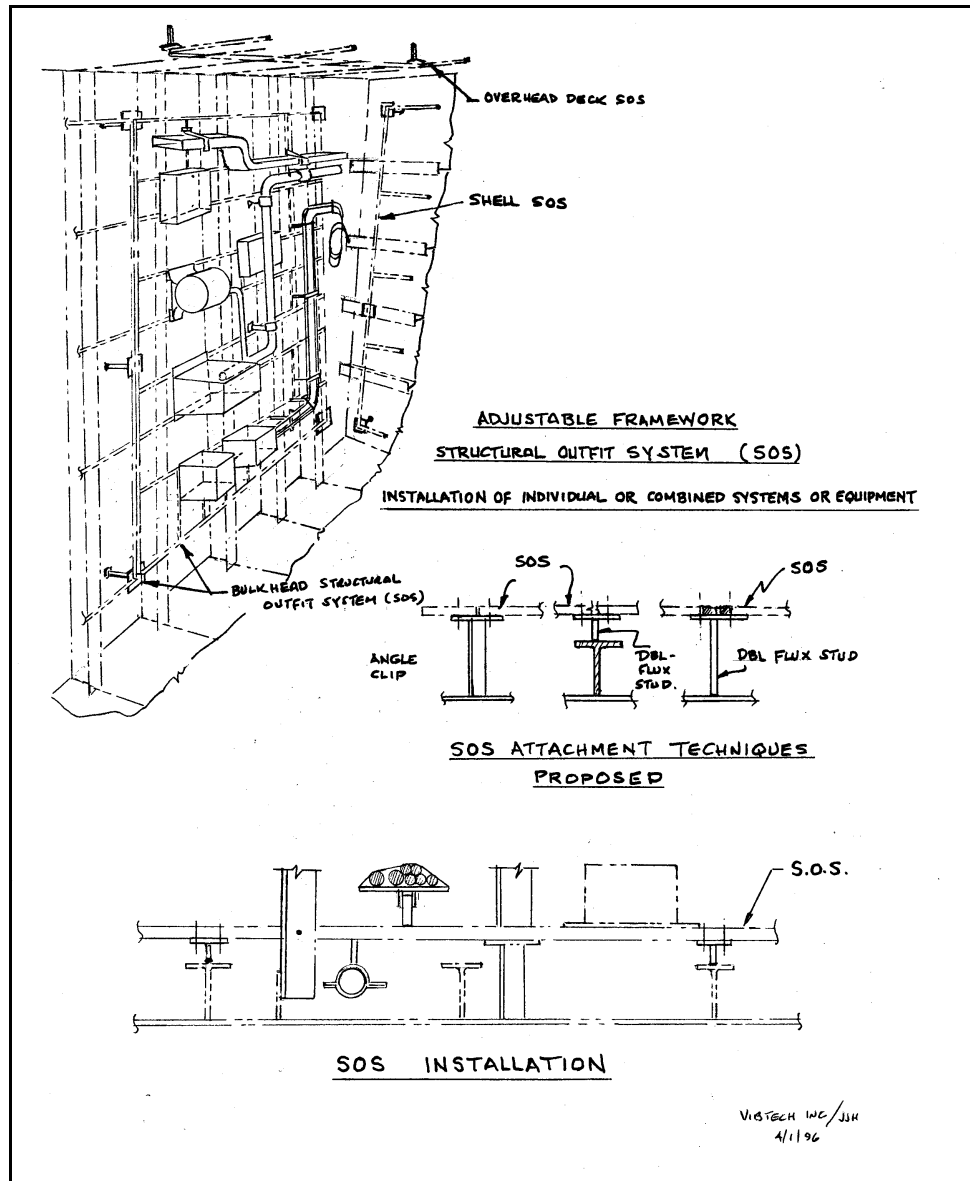


Figure 6-1 — Lattice System Installation Concepts

PIPING SYSTEM INSTALLATIONS

We have developed alternates to traditional all-welded piping systems to facilitate blast and paint, fitting insulation and final installation of piping systems. See Figure 6-4 for candidate piping system installation detail concepts.

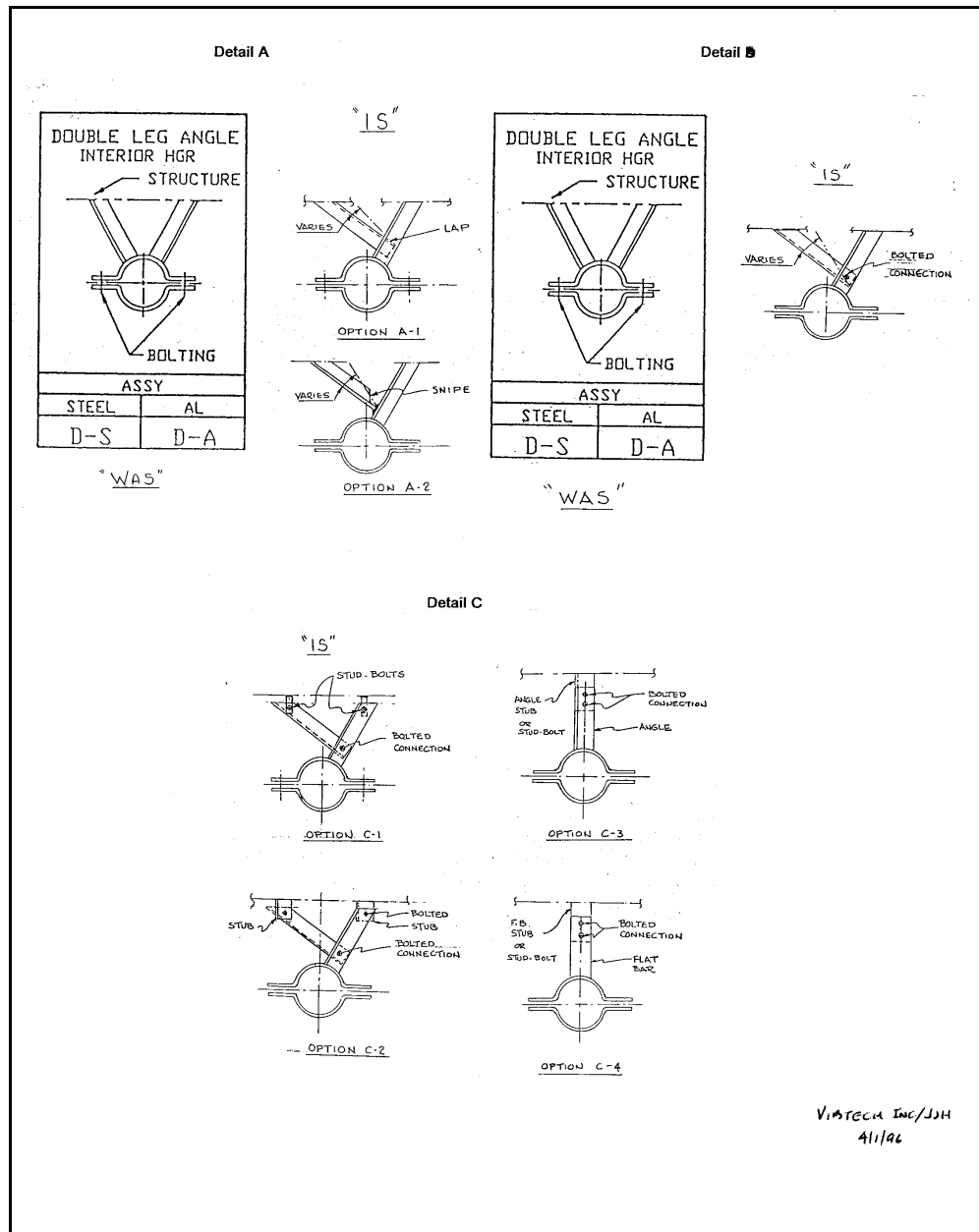


Figure 6-1 — Pipe Hanger Design Alternates

Vibtech Inc. believes that, with a proper mathematical characterization of piping system and hangers and the use of high strength materials, significant economies in hanger design, See Figure 6-4, can be achieved as follows:

1. Unnecessary backup structure and pads in way of hangers can be eliminated.
2. Sway Braces or lateral support for small diameter pipe can be removed, i.e. '1/2" IPS through 3/4" [PS. (DDG-51 quantity = 920)
3. Type D hangers may not be required for 1" IPS through 2" IPS pipe sizes for stand-off lengths up to 24 inches. Type C hangers may be used in lieu of Type D
4. Hangers Scantlings can be reduced and greater standardization can be achieved; clamp thickness can be reduced and significant weight savings can be achieved.
5. Manufacturing simplification can be achieved for Type D hangers. A single downcomer leg may be welded to the clamp and the sway brace lap welded to the downcomer at the proper angle. (See Detail A)
6. Installation simplification can be achieved by developing design standards using bolted attachments of the sway brace to the clamp downcomer, (Type D). (See-Detail B)
7. Mechanical attachments can be developed for all hanger systems to facilitate blast and paint, fitting insulation and final installation of piping systems with hangers in PO-2 to improve the hot pre-outfit (PO-1) schedule, blast and paint schedule and pre-outfit (PO-2) schedule. Final installation of pipes and hangers can be shifted to the cold pre-outfit stage of construction. (PO-2). The procedure will permit outside/shop manufacture of pipe hangers with final paint/preservation of the hangers before installation of piping and hangers. (See Detail C)

ELECTRICAL SYSTEM INSTALLATIONS

Alternatives have been developed to electrical system installations to facilitate blast and paint, fitting insulation and final installation of cableways and cable. See Figure 6-5 for alternative methods for supporting the cableways.

STUD MOUNTING PLATE METHODS

Bolt studs and alternative methods can be used to mount equipment and systems. These range from stud-bolts that can be manufactured in various length to facilitate standards development for both pipe and cable hangers, See Figure 6-5, through to double flux type studs that can expedite the attachment of equipment and outfit, See Figure 6-6.

SMART SYSTEMS (SHIPBOARD MODULAR ARRANGEMENT RECONFIGURATION TECHNOLOGY)

The SMART system uses a modular track system with an attachment assembly to install systems and components. A description of the system is included within this section.

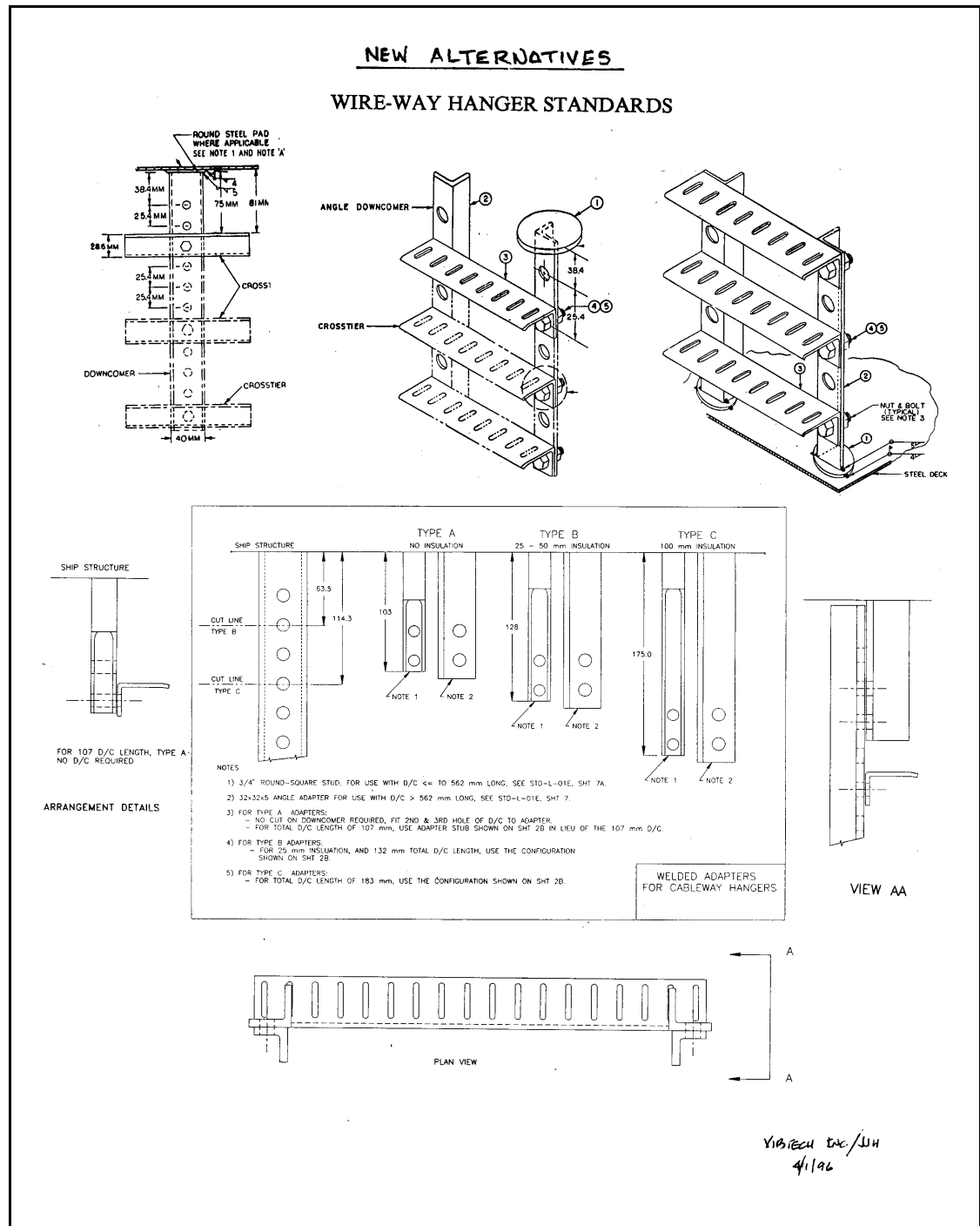


Figure 6-1 — Cable Way Hanger Attachments

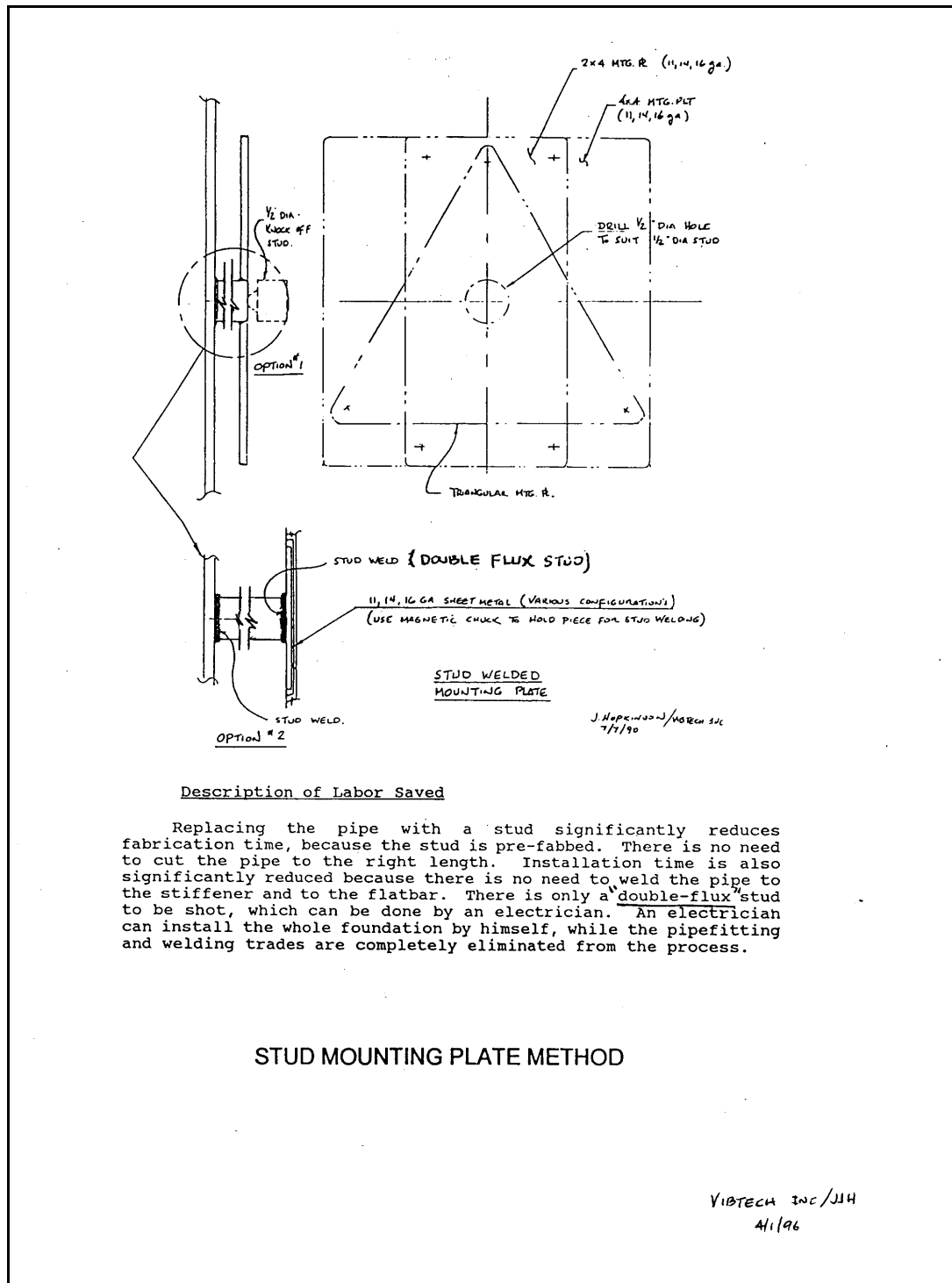


Figure 6-2 — Stud Mounting Plate Method

HILTI SYSTEM COLD-WORK ATTACHMENT METHODS

Hilti Corporation has developed a number of fastening systems for industrial and marine applications that support the concept of quick attachment methods for shipboard use on foundations and system attachments. Their systems include Powder-Actuated Fastening, Screw Fastening Systems and Anchor systems. They have developed a channel installation system that will facilitate the lattice work system discussed previously. A description of the system components and some applications is included herewith.

JOINER BULKHEAD ATTACHMENT METHODS:

OVERVIEW

Metal joiner bulkheads were originally designed to act as compartment boundaries and could not sustain very high loads. They were capable of carrying only 30 pounds of equipment for each 4-foot x 8-foot panel while sustaining a shock load. However, in the early 1970's, during the FFG-7 detail design, it was demonstrated that joiner bulkheads could be designed to sustain up to 350 pounds while being subjected to shock. A major benefit of the FFG-7 design development was that nearly 400 deck-to-deck foundations were eliminated by directly mounting equipment to the joiner bulkheads.

As design development continued over the years, appropriate design tradeoffs were made to consider a full load shock-hardened capability versus a reduced capability in order to provide a graduated shock performance structural capability. This graduated capability was considered necessary in order to provide the requisite structural load capability where equipment weights were known. Where future upgrade/future growth flexibility was considered necessary for planning purposes, a minimum shock performance could be provided. Consequently a structural capability to carry 350 pounds and 150 pounds for full load and minimum load, respectively in a grade "A" shock environment was established as a standard by virtue of the example set by the FFG-7 class ships. In order to assess the bulkheads for the purpose of this trade-off, the following rating system was used:

- | | |
|-------|---|
| 1.0 = | Bulkhead is full-load shock rated. The joiner bulkhead system can support a 350-pound shock load without further development. |
| 0.8 = | Panel can definitely support the minimum (150-pound) load and the maximum (350-pound) load with appropriate development. |
| 0.6 = | Panel will require moderate development and testing in order to achieve a minimum and maximum load rating. |
| 0.4 = | Panel will require development to be able to support the minimum load, and will probably not be able to support the maximum load. |
| 0.2 = | Bulkhead system will only support the required 30 pound load under grade "A" shock. |
| 0.0 = | Panel will not support any load. |

For the purpose of this report, only single-faced fasteners are described, since through-bolting may be unacceptable in decor areas. The load carrying capability of a panel is mainly a function of the thickness of the face sheet for single-face fastener systems. With the use of through-bolting and better design of attachment to coaming and curtain plate tracking systems, it is conceivable that the load carrying capability could be enhanced significantly. For single-face fasteners, the load carrying capability could go as high as 350 pounds under grade

"A" shock. Commercial loads could be much higher due to lower "g" factors. Panel attachment to the tracking system would have to be redesigned and equipment fastener system would have to be designed to take this load.

It has been established that extruded aluminum panels, both 0.055-inch thick (2 psf) and 0.072-inch thick (3 psf) as well as the 0.045-inch thick face sheets on the aluminum honeycomb panels can support the maximum 350-pound load under grade "A" shock. These results have been substantiated by tests and are accepted for use by Navy. Since any 0.045-inch thick aluminum-faced panel can withstand the maximum required load, it follows that the aluminum-faced Nomex can as well. Using similar methods of calculation to determine an equivalent load carrying capability panel, a 0.025-inch thick steel face on a Nomex core can handle a 150-pound loading under grade "A" shock. For a steel panel that is equivalent in weight to an aluminum honeycomb panel, a 0.016-inch thick steel face can also carry 150 pounds under grade "A" shock. Thus, any of the panels that have a 0.025-inch steel face or a 0.016-inch steel face can carry loads of up to 150 pounds. Calculations from manufacturers indicate that GRP Nomex is also be able to carry a 150-pound load under a grade "A" shock, and will be able to go as high as 350 pounds with some development. Because of Marinite's unique structure, single face fasteners could not carry any load at all under a grade "A" shock loading, because the equipment would have to be attached with screws into the panel and the plaster-like composition could not handle the stresses considered.

Through bolting, along with the use of backing plates and other methods, enhances the load carrying capability of the panels considerably. The 0.016-inch steel-faced panel could conceivably carry a 350-pound grade "A" shock load. The present method of attaching equipment to Marinite is to run a steel beam behind the panel, supported by a separate foundation, and attach the equipment directly to the beam through the panel. This is contrary to the whole idea of eliminating the through-bolting method to reduce weight and cost.

Another facet that should be considered is the panel's load carrying capability when subjected to fire. Aluminum-faced panels performed the worst in this area. After 3.5 to 5 minutes into the fire (as defined by the ASTM E-119 fire test), the aluminum panels melted. Typical damage control response time to a fire is 6 minutes. Thus, system failure would occur and all equipment would be lost before there could be a response to the fire. GRP extends this burn through time to 30 minutes, but failure under a load would occur at no less than 0' to 7 minutes depending on the magnitude of the load. The problem is that the resin burns out of the glass, reducing the panels structural strength.

Steel-faced panels perform better than the other candidate bulkhead systems when subjected to fire, since steel neither decomposes nor melts at these temperatures. Steel is much better than GRP Nomex, and GRP Nomex will last about three times as long as aluminum under fire conditions with a load. The Coast Guard conducted C,P,O, berthing compartments burnout tests, which followed the ASTM-119 fire test for the first several minutes. The aluminum melted at 3 to 5 minutes, GRP panels maintained their integrity except in areas where the fire directly impinged on the panel, Steel-faced panels showed no signs of structural failure anywhere. The steel panels used in the C,P,O, burnout tests were steel-faced Nomex,

FIRE CONTAINMENT

In the event of a fire aboard ship, combat capability can become greatly impaired if the fire spreads beyond of the confines of the compartment in which it originated. A joiner bulkhead system is considered a good fire stop if it is able to contain a fire until damage control has time to respond. Any containment time less than the time it takes to detect the fire is considered a poor fire stop. Typical response times range from 8.5 minutes to 13.5 minutes, including a 3.5 minute detection time. For the purpose of a trade-off, containment time of 30 minutes is considered the "top end" of the scale since any fire contained in one area for that length of time could certainly be put out by damage control.

Since welded CRES honeycomb, extruded aluminum, and Marinite are inorganic, they do not burn or smoke. Coast Guard compartment fire tests showed that Marinite panels contained the fire throughout the life of a 45-minute test. In another Coast Guard full-compartment burn test, six tests were conducted to determine fire and smoke containment capability of various joiner bulkhead systems. Core material for each of the test bulkheads

was Nomex aramid honeycomb, filled with a phenolic foam. Three bulkhead face materials were tested: phenolic resin impregnated fiberglass, galvanized steel, and painted steel. The Coast Guard test simulated a "worst-case" situation without being unreasonably severe. Good control was maintained over the test conditions, consistent with cost constraints. Time- Temperature relationships observed in the testing were compared to the standard fire test method, ASTM -119. While the temperatures in the six fire tests show variability, factors such as the timing and extent of ceiling panel collapse, warpage of bulkhead panels within the tracking system, and heat absorption could not be controlled without decreasing the realism of the test.

FASTENER TESTS

As a basis for establishing the strength of fasteners attached to the honeycomb bulkheads a number of types of fasteners may be attached to small sections of honeycomb bulkhead material in order to be tested independently in tension and shear. The results of these tests are evaluated to establish the design criteria for the strength of the fastening system used to attach equipment to the honeycomb panel.

TENSILE LOADING FAILURE MECHANISMS

For fasteners attached to one face sheet of a honeycombed panel (i.e. single 3/16" diameter pop-rivets and various size press nuts without pads) and subject to a tensile load (load applied normal to the panel): failure occurred by pull out of the fastener. For fasteners attached to a single face sheet with pop riveted pads (i.e. 1/2" and 3/4" welded studs on steel pads and various size Rivnuts with pads) failure occurred by delamination of the face sheet from the honeycomb core. For bolts installed through the honeycomb panels the core collapsed locally in way of the bolts. When Aeronca conducted similar tests on 1/4" dia bolts through honeycomb panels they recorded the load at which the panel began to yield locally (core collapsing in way of bolt) as well as the ultimate tensile load required to pull the bolt through the panel.

SHEAR LOADING FAILURE MECHANISMS

The same types of fasteners as tested above were also subjected to applied shear loads. In three cases the fasteners failed in shear: the 1/4" dia bolts threaded into rivnuts installed in honeycomb panels with and without riveted pads failed, the single 3/16" dia pop rivets failed, and the pop rivets attaching the pads with welded studs failed when only four pop rivets were used. All other failures resulted from local failures of the honeycomb panels in way of the fasteners. For bolts larger than 1/4" and threaded into press nuts and rivets which were installed in one face (with no pads) breaking failure of the face sheet occurred, accompanied by local core crushing due to rotation of the insert in the panel. For rivnuts larger than 1/4" dia bolt capacity and inserted into one face through pop riveted pads, failure occurred by panel buckling due to the overturning effect of the eccentrically loaded bolts. There was no evidence of bearing failures in the panel face sheets in way of these fasteners. When a shear load was applied to 1/2" and 3/4" studs welded to steel pads the pop rivets attaching the pads to the honeycomb panels failed in shear if less than 4 pop rivets were used. When 8 pop rivets were used failure occurred by panel buckling similar to that observed for rivnuts through pads. For the 5/8", 1/2" and 3/4" dia through bolts (no pop-riveted pads) bearing failures occurred in both faces of the panel. In all cases the through bolts rotated in the holes due to the eccentrically applied shear loads. When pop riveted pads were installed on the side of the applied shear load the panels again buckled (except that when only 4 pop rivets were used to install the pad and the 3/4" dia through bolt was tested all four pop rivets sheared and bearing failures at the bolt in both panel faces). In general, the ultimate failure loads were those loads that caused local panel failures in way of the fasteners (face sheet bearing failure, core crushing and local panel buckling). The only cases where actual fastener failures were recorded were the shear failure of pop rivets (either alone or fastening pads to the panels) and the shear failure of the 1/4" dia bolts threaded into rivnut inserts.

CONCLUSION

The results of the tests as outlined in the preceding two paragraphs indicate that the honeycomb panel face sheet failure rather than actual fastener failure is the predominant mode of attachment failure. In order to account for the interaction of the tensile and shear loads when applied to the honeycomb attachments simultaneously suitable interaction equations have been developed.

INTERACTION EQUATIONS

It must be first noted that all tensile and shear tests were run independently. It is therefore impossible to draw any conclusions as to the interactive effects of combined tensile and shear loading from the test program. In order to determine the ultimate strength of the various honeycomb fastener configurations under combined tension and shear the stress ratio interactive curve method developed by Shanley was employed. In this method the stress conditions on the honeycomb face sheets are represented as stress ratios. For a simple stress, the stress ratio can be expressed as,

$$R = \text{Stress Ratio} = f / F$$

Where f is the applied stress and F is the allowable stress

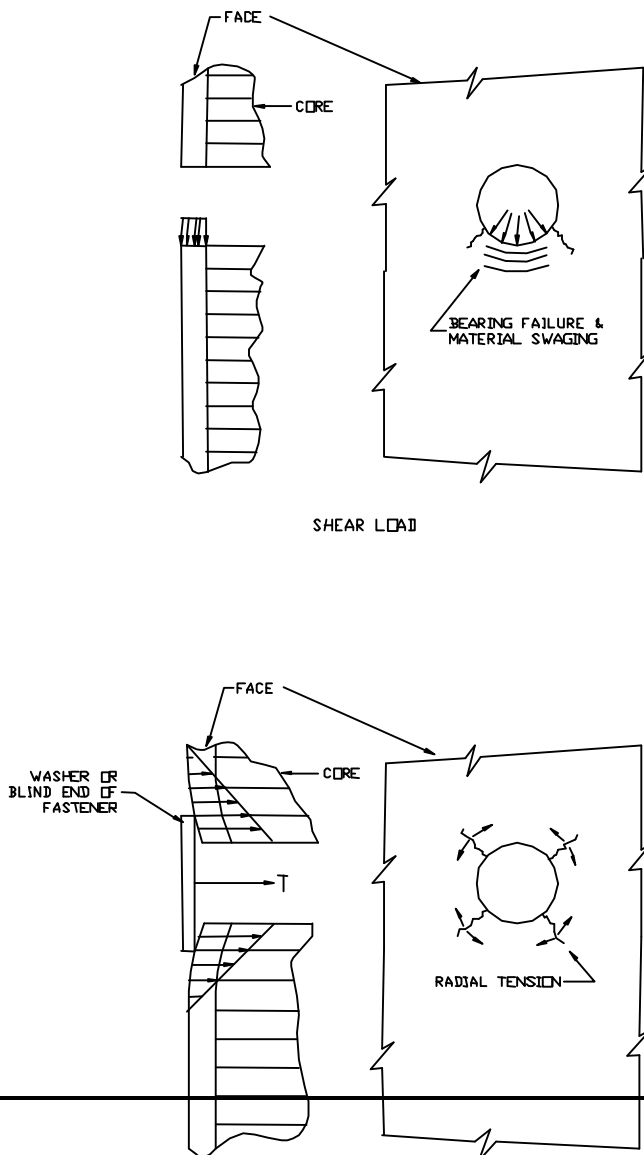
For combined loading, the general conditions for failure are expressed by Shanley as

$$R_1^x + R_2^y + R_3^z = 1 \quad (1)$$

R_1 , R_2 , and R_3 could refer to tensile, bending and shear. The exponents give the relationship for the combined stresses. The exponents of the stress ratios in the above equation can be determined by various well-known theories of yield and failure. However in many cases of combined loading for specific structural configurations the exponents must be determined by making failure tests of the combined load system. The interaction equation may also be written in terms of load ratios rather than stress ratios. Where f is the applied load and F is the maximum allowable load.

DUE TO SHEAR LOAD

Considering the panel face as a stiffened web plate it can carry a shear load larger



than the load required to cause local crippling (buckling) in way of the hole.

If the bearing stress is not limited to the bearing capacity of the face material, local buckling bearing failure in way of the hole would be the anticipated failure mode.

Due to Tensile Load

Maximum transverse shear occurs at the periphery of the washer. This shear decreases in intensity away from the washer due to larger area involved. This maximum shear does not occur at the point of maximum bending.

CONCLUSION

The above sections show the typical types of loading expected in the honeycomb face sheets in way of the fasteners. It can be seen that the predicted maximum bearing load, transverse shear load and bending moment do not occur at the same point. Well known theories of yield and failure give techniques for calculating the combined stresses resulting from the bearing load, transverse shear and bending moment but they give no techniques for adding the effects of radial tension and material swaging in way of the fastener. It is obvious that these effects can combine to lower the effective strength of the various fastener configurations. Because no methods other than actual testing are available to account for these effects the BIW testing program was devised to give ultimate failure loads in tension and shear independently. To account for the interactive effects of these two load cases, since no combined load cases were tested, the most conservative form of Equation (1) was chosen:

$$R_1 + R_2 + R_3 = 1 \quad (2)$$

The exponents x, y, and z were set to one. R_1 equals the ratio of the applied tensile load to the allowable tensile load and R_2 equals the ratio of the applied shear load to the allowable shear load.

The final form of equation (1) to be used is as follows:

$$T / T_{allow} + S / S_{allow} < 1 \quad (3)$$

ROBOTICS FOR EQUIPMENT AND SYSTEM INSTALLATIONS

OBJECTIVE

Develop applications for robots to assist the installation of equipment and systems, especially portable robots consistent with constraints imposed by robotic operations, construction accuracy standards and candidate hull structure and outfitting details.

BACKGROUND/APPROACH

Robots may be constrained to those details where it is relatively easy to achieve the construction accuracy standards necessary to successfully employ robots. In order to be effective, structural geometry accuracy must be maintained to close tolerances, typically less than 1/16". However, it may be possible to broaden the use of robots through the use of standard construction details for both structure and outfit and especially equipment and system installation standards and to hold the manufacturing of these details to tolerances that can support the use of "teach" robots. The use of teachable/programmable robots would employ the use of "Teach Pendants" in association with 3-D vision and software programming for the selected standards..

The standards would be programmed with the use of a 3-D product model that would describe the tool path for the robot, whether a welder or other tool that would be utilized to install the quick attachment fasteners that may be used for equipment and systems. The resultant "MAP" would be used by the robots 3-D vision system to guide the robot. The Teach Pendant would provide the robot with the initiation and termination of the welding, drilling or other operations sequence. The robot would compare the "standard" map of the weld/drilling/ops geometry with the 3-D vision of the actual weld/drilling/ops and make adjustments in the tool to account for differences (skewness & other characteristics) in order to complete the weld or other construction sequence.

The robot with "3-D" vision capability will sense the fabrication geometry and tool path based on the software map of the standard structural or outfit detail. The Teach pendant will orient the robot to its work and would both provide where the weld will be initiated and where it will be terminated. Since the tool path will be based on a standard, increased flexibility can be built into the software controlling the ability of the robot to respond to the differences between the 3-D perceived geometry and the standard map geometry.

Since even standard parts are not identical, the robot must be programmed to adjust to an ever-increasing tolerance range on the set of geometrical data for each standard. Identification of current state-of-the-art geometry constraints for robots should be developed in association with robot manufacturers. Improvement in the ability of robots to follow programmable tool paths for standard structural and outfit details and make adjustments for "actual" distortions, skewness and irregularities will usher in advanced applications for robots.

TECHNICAL APPROACH

1. Identify Robotic operations, capabilities, limitations in following prescribed tool path. Characterize state of the art in 3-D vision systems and teachable robots
2. Define parameters for the constraints on robots, standards, 3-D vision systems and teach pendant systems.
3. Identify Candidate structural standards and outfitting system equipment and system installation standards and applications that would be amenable to be constructed with portable robots.
4. Select Candidate structural/ outfitting details, portable robotic systems, 3-D vision systems and teachable control systems to develop candidate applications for portable robotic systems.
5. Develop selected standards for portable robots using 3-D vision systems and teach pendants. Program software tool paths for the advanced portable robots using newly developed standards.

6. Develop demonstrations of portable robotics for candidate structural/ outfitting standards.

APPENDIX A — SMART SYSTEMS

SMART SYSTEMS

Shipboard

Modular

Arrangement

Reconfiguration

Technology



SMART SYSTEM COMPONENTS

- **SMART Track/Deck**
 - Track
 - MIL Track Installation
 - COTS Track Installation
 - Fittings
- **Modular Furniture**
- **Modular Power**
- **Modular Lighting**

TYPICAL SMART SYSTEM INSTALLATION

- Determine candidate SMART Deck space using Modular Track Systems Criteria Matrix
- Perform deck/bulkhead survey to determine area & track orientation, and Hard vs. Soft Track requirements.

HARD TRACK [MIL SPEC]

- Size & Install Hard Track Foundation Support System

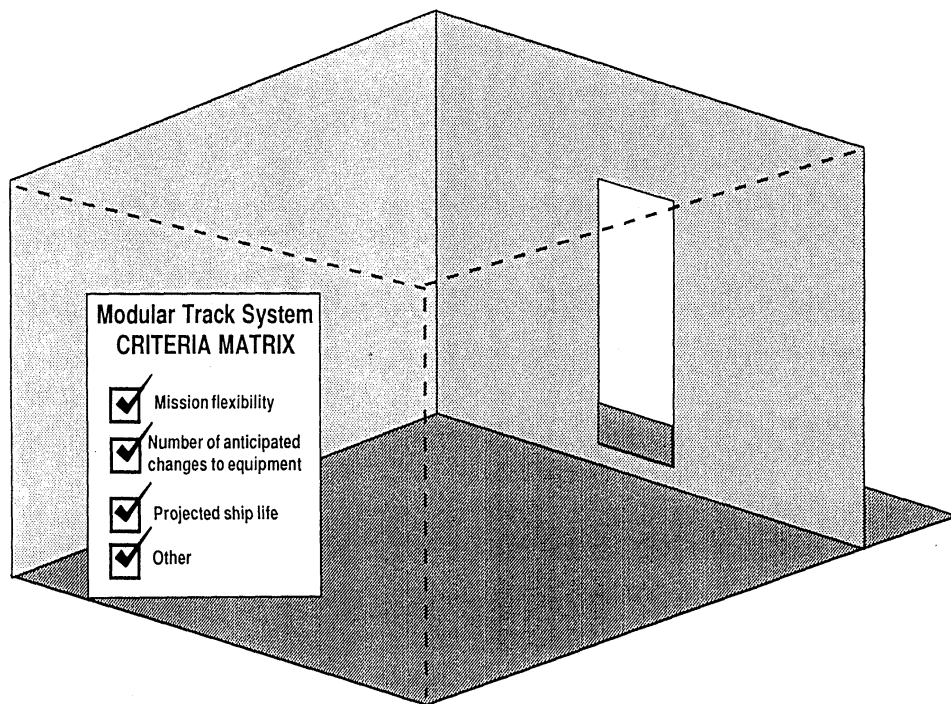
OR

SOFT TRACK [COTS]

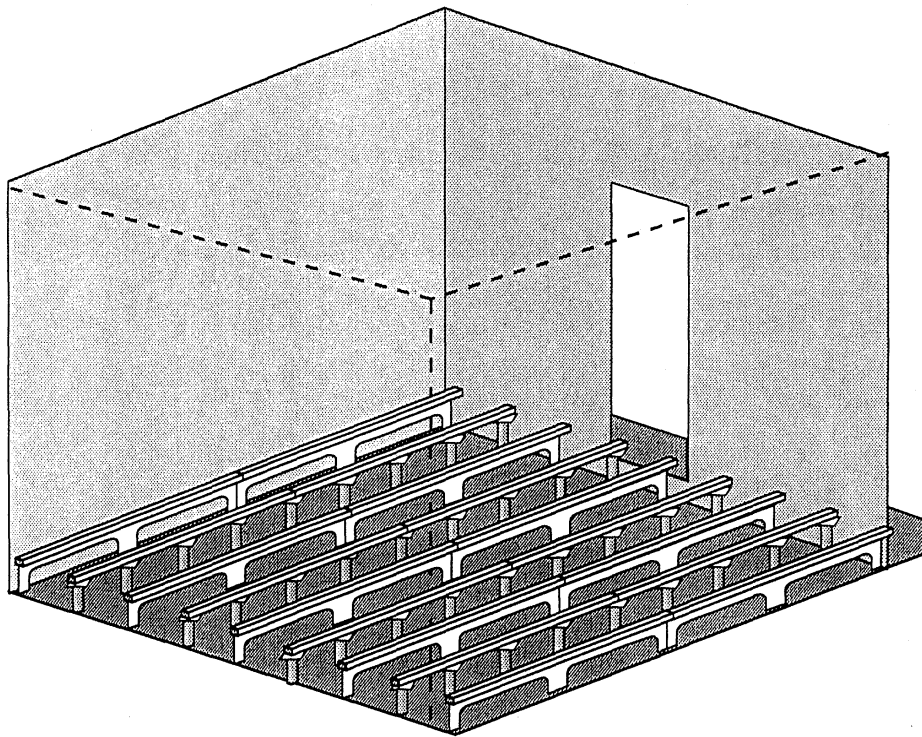
- Weld or Bolt Soft Track Foundation Support System

- Install Track Adapters
- Install SMART Track
- Install Longitudinal Supports
- Install Deck Panels/Filler Strips
- Install Equipment Foundation Fittings and Adapters
- Install Equipment Foundations and Equipment

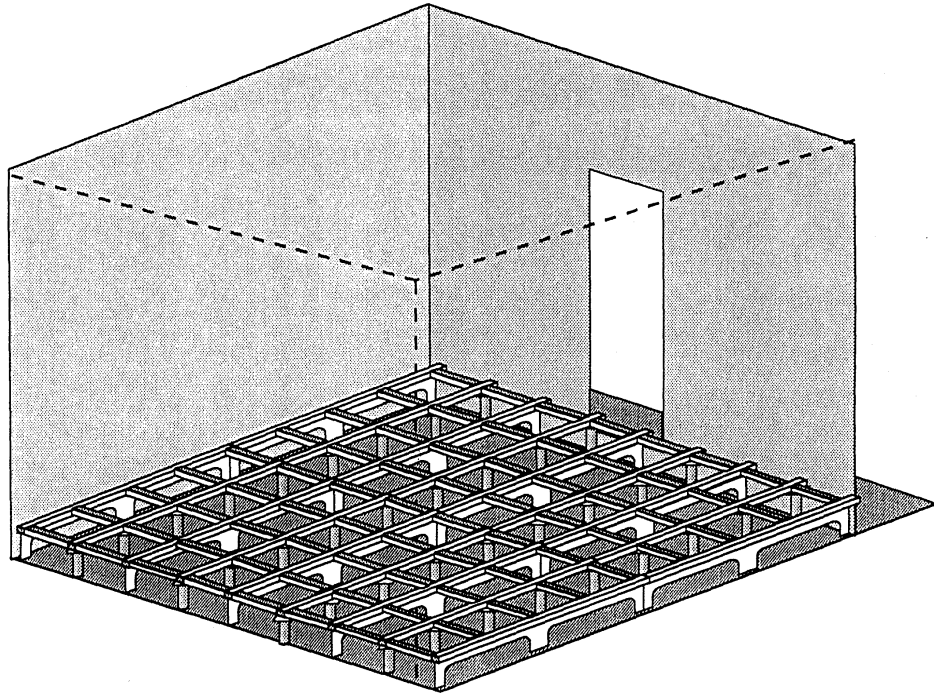
DETERMINE CANDIDATE SMART SPACE



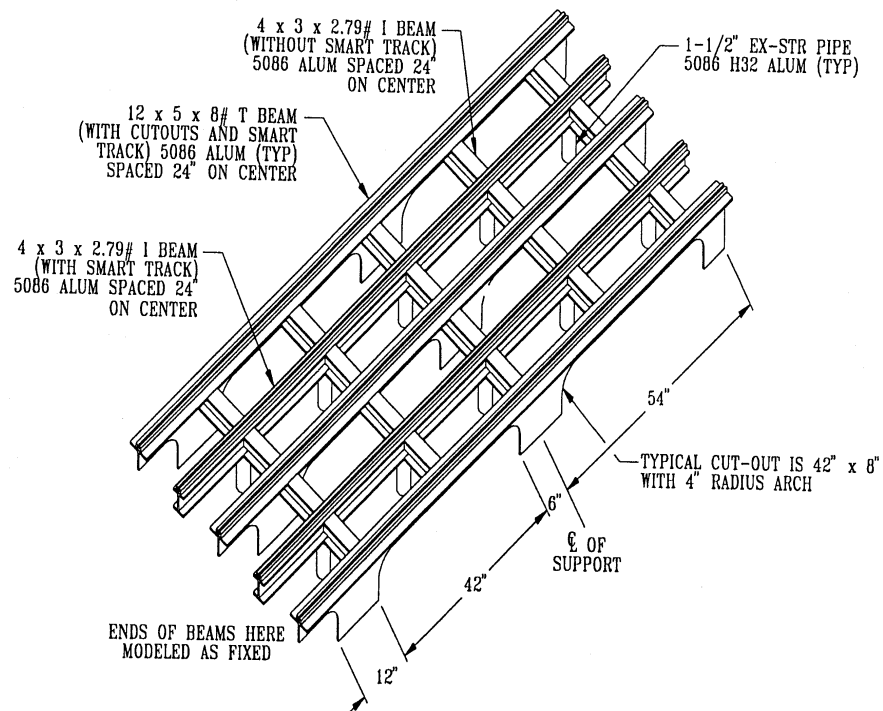
H/D SMART TRACK INSTALLED ON “HARD TRACK” FOUNDATIONS



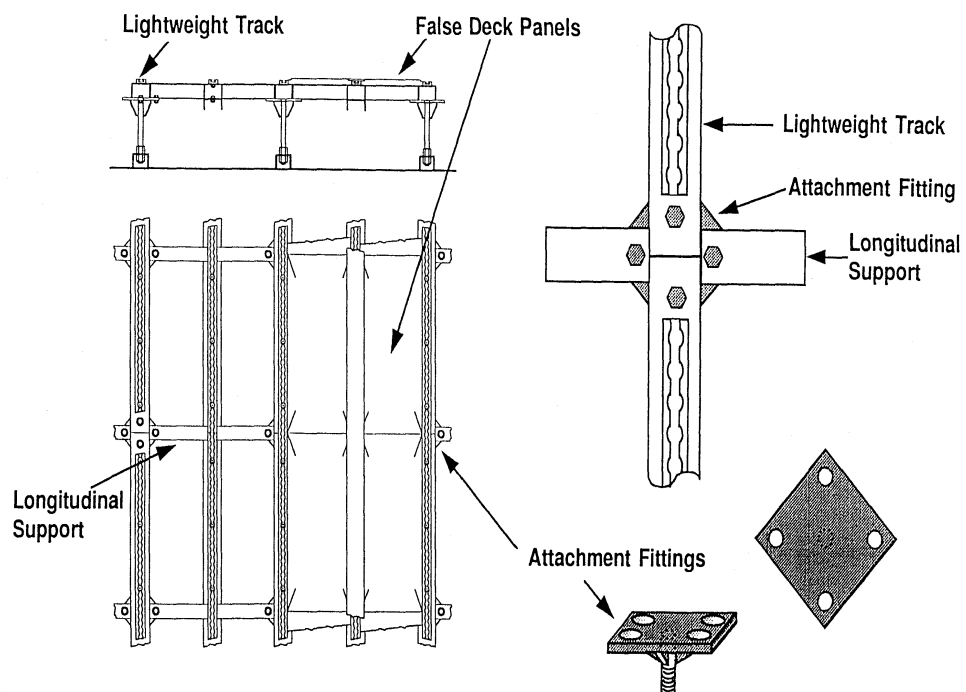
**“HARD TRACK” LONGITUDINAL
SUPPORTS INSTALLED**



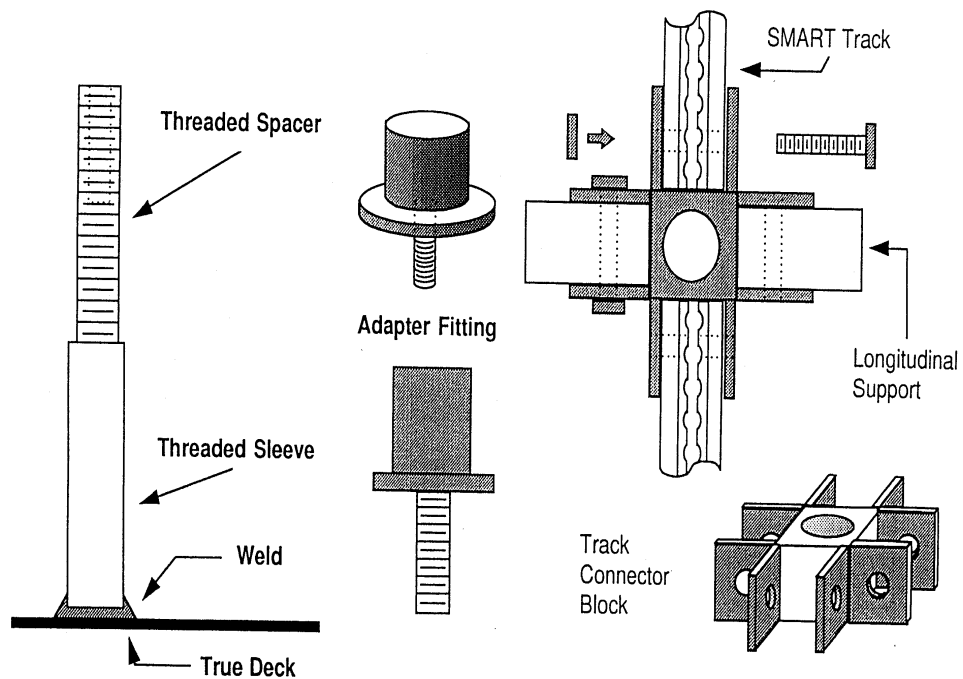
DETAIL OF HEAVYWEIGHT MILSPEC "HARD TRACK" ASSEMBLY



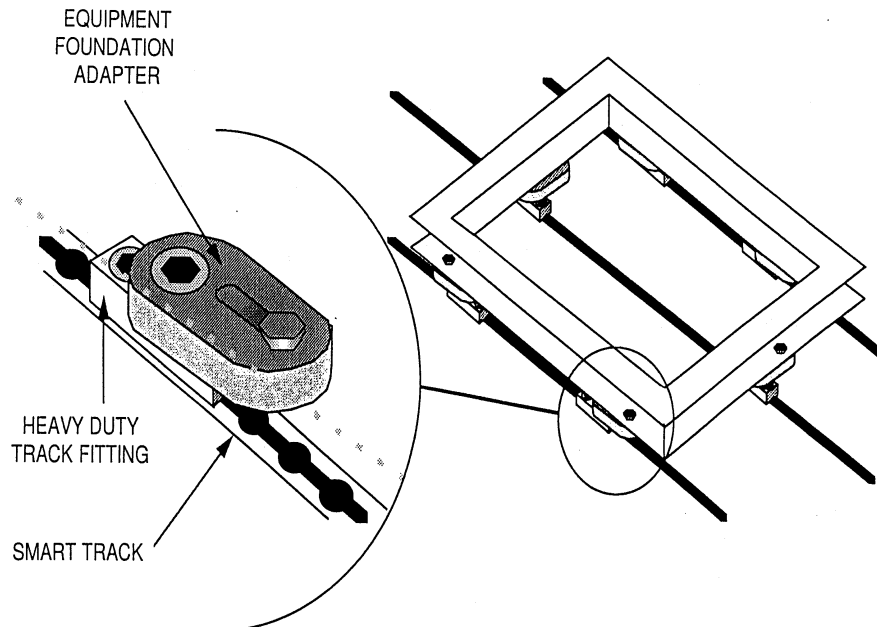
LIGHTWEIGHT "SOFT TRACK" & FALSE DECK ASSEMBLY



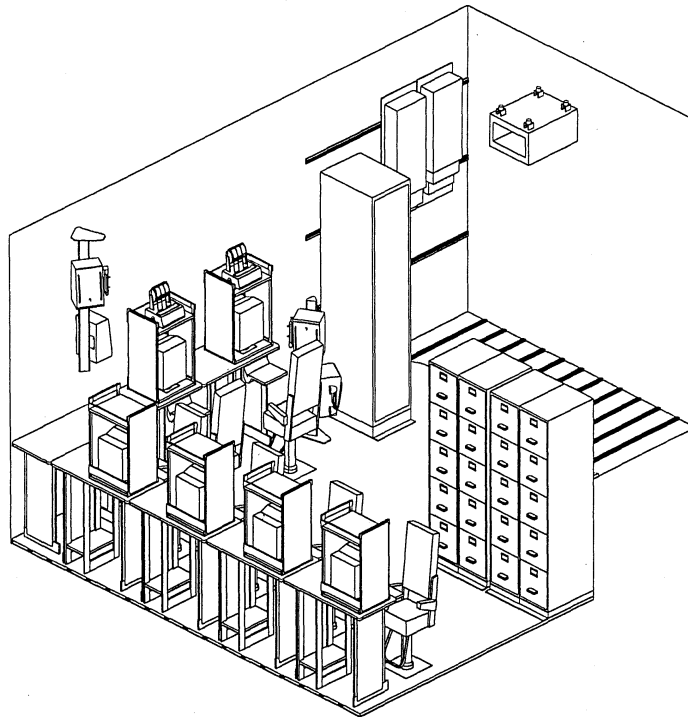
MEDIUM/HEAVY WEIGHT SPACER, ATTACHMENT FITTING AND ASSEMBLY



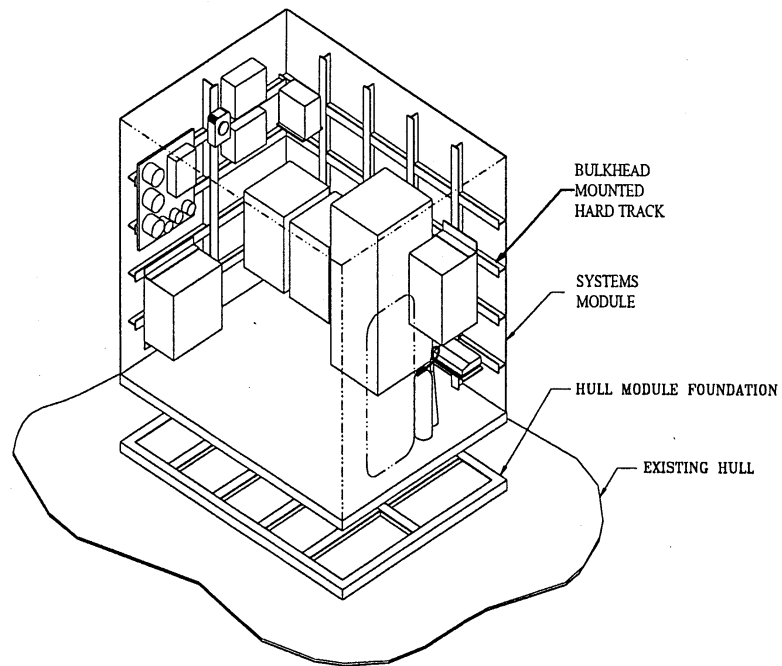
**TYPICAL EQUIPMENT FOUNDATION WITH HEAVY
DUTY TRACK FITTINGS & FOUNDATION ADAPTER**



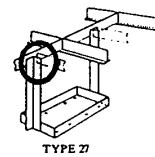
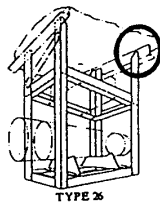
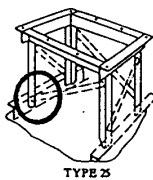
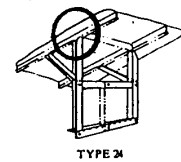
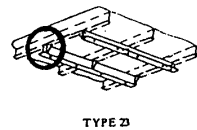
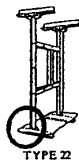
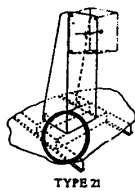
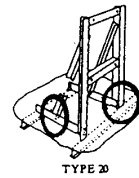
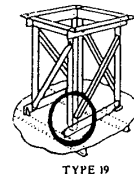
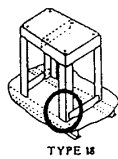
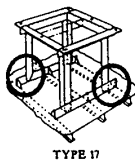
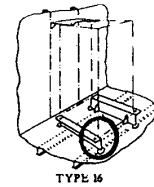
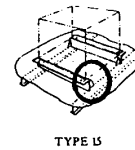
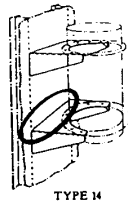
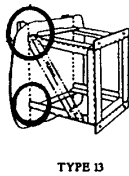
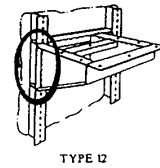
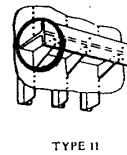
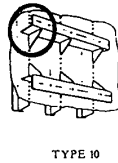
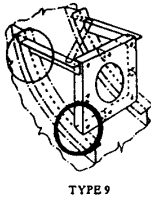
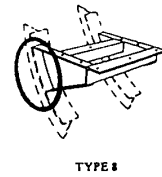
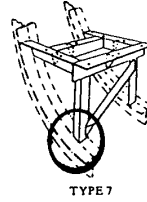
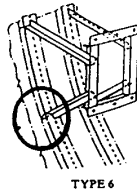
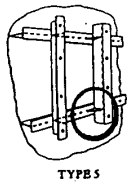
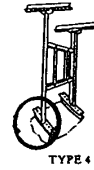
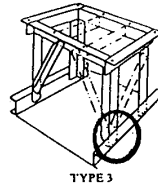
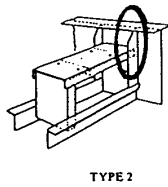
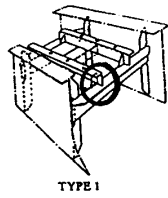
SMART SPACE: INCORPORATES SMART DECK,
SMART EQUIPMENT FOUNDATIONS, AND MODULAR
POWER DISTRIBUTION, LIGHTING AND FURNITURE



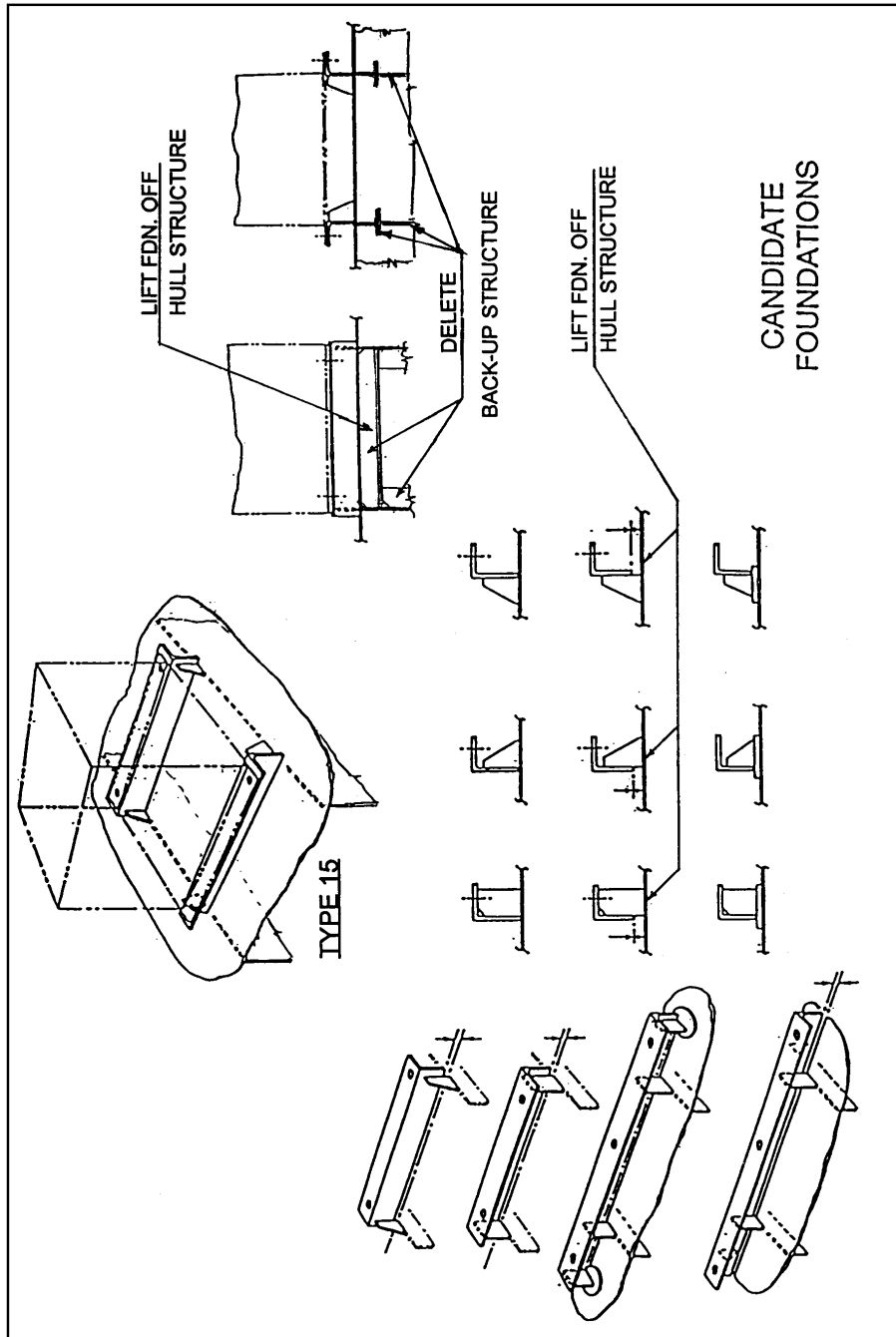
**PREFABRICATED SMART SYSTEMS MODULE:
EQUIPMENT CAN BE PRE-ASSEMBLED OFF-SITE FOR
INSTALLATION/INTEGRATION AT SHIPYARD**

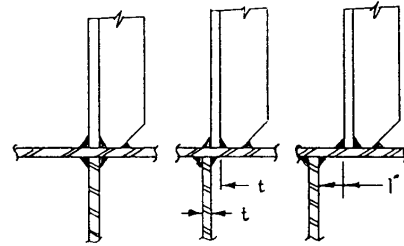
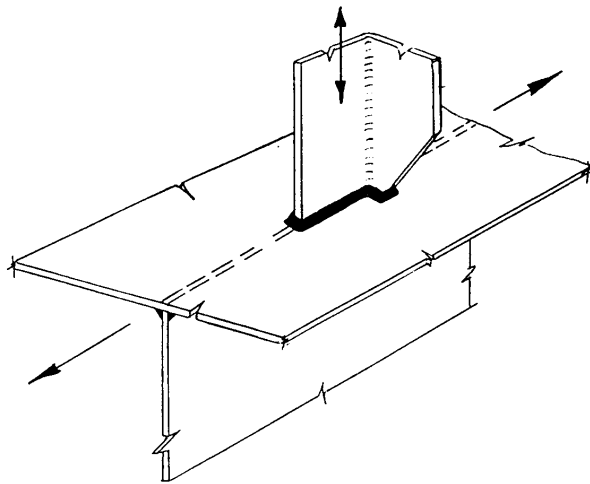


<p>APPENDIX B — FAMILY OF FOUNDATIONS WITH ALTERNATIVE ATTACHMENT TECHNIQUES</p>

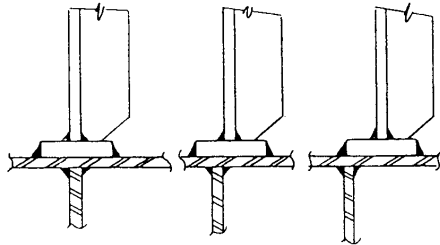


Family of
Foundations

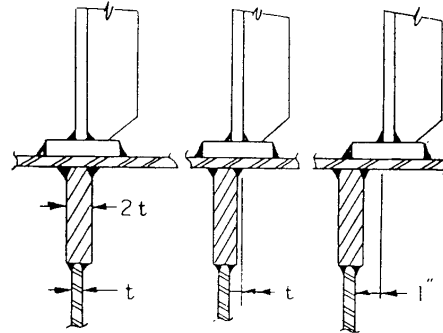




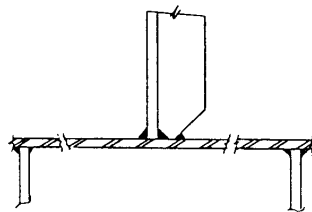
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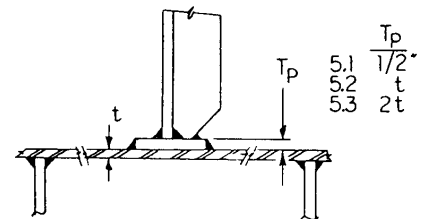
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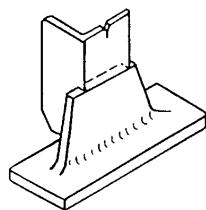
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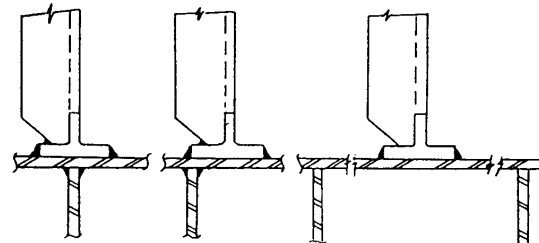
SET 4



SET 5

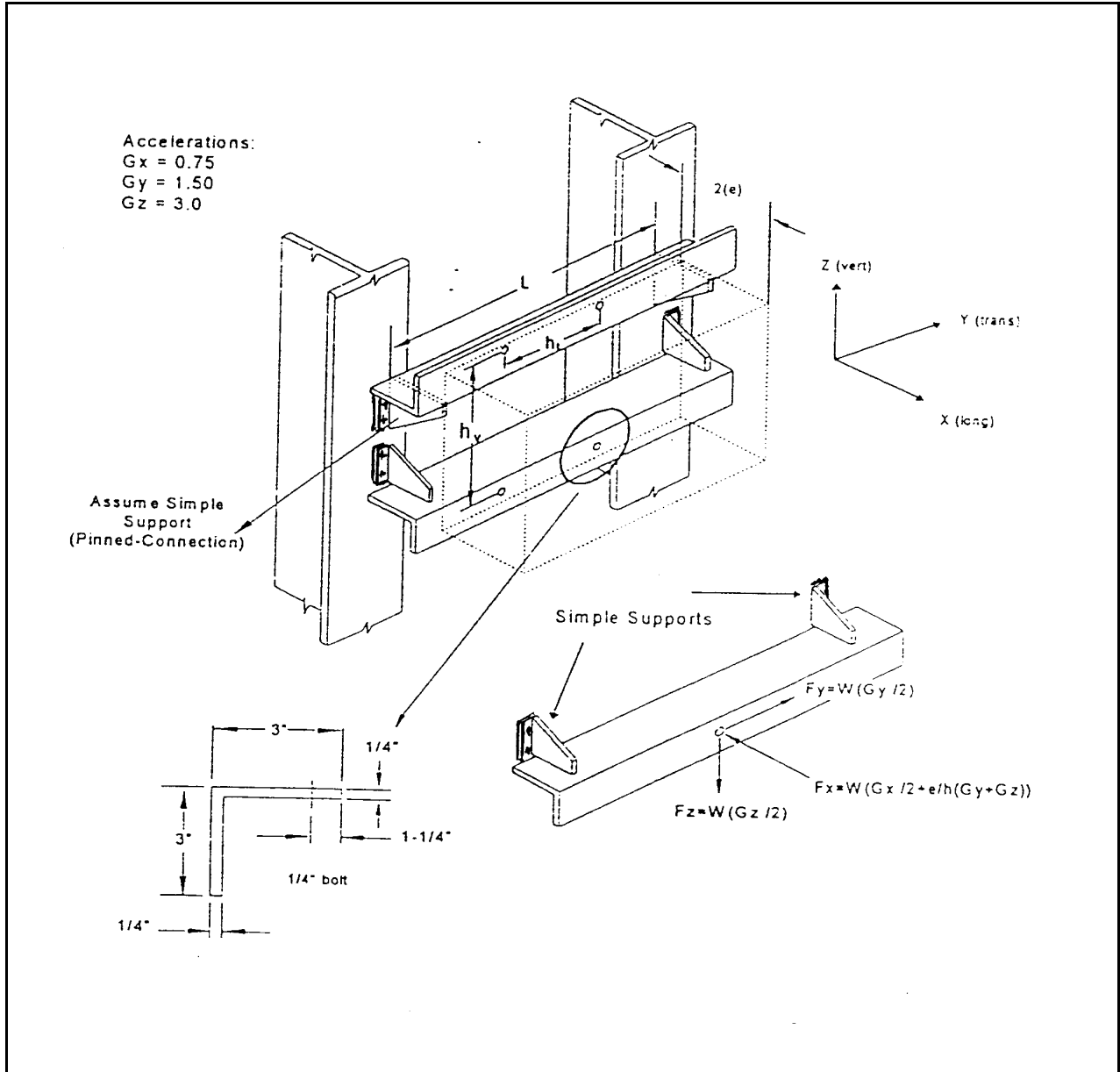


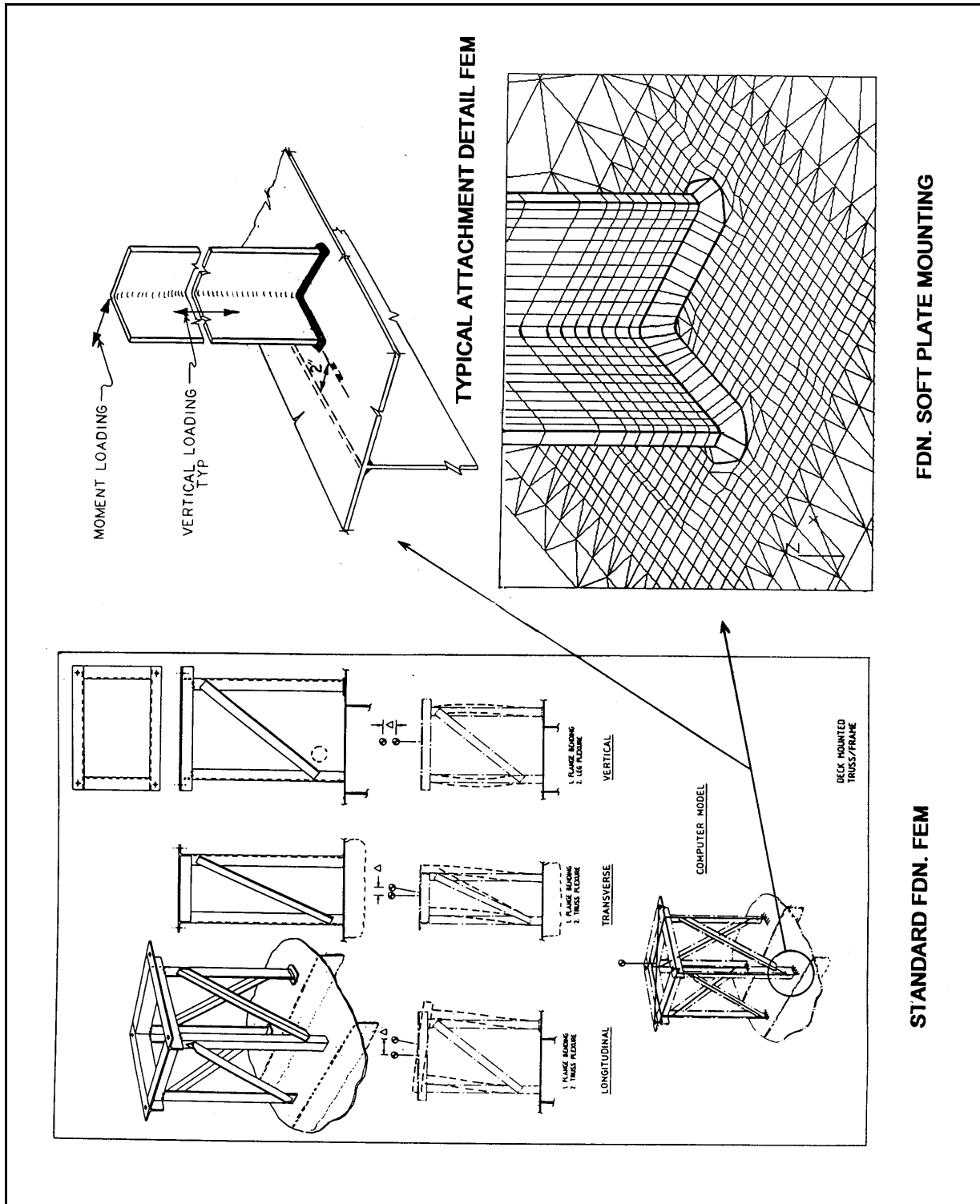
UNIVERSAL PAD



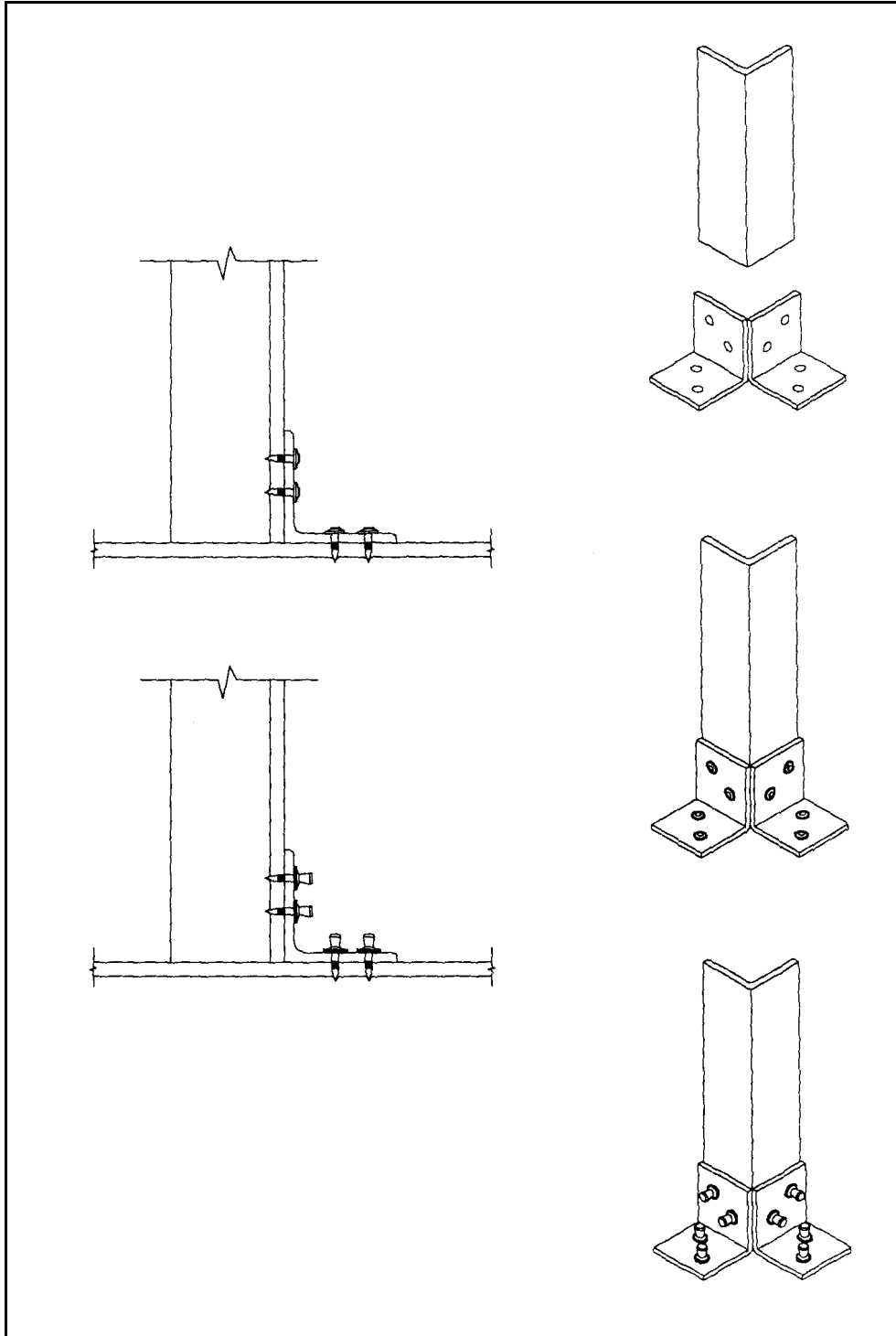
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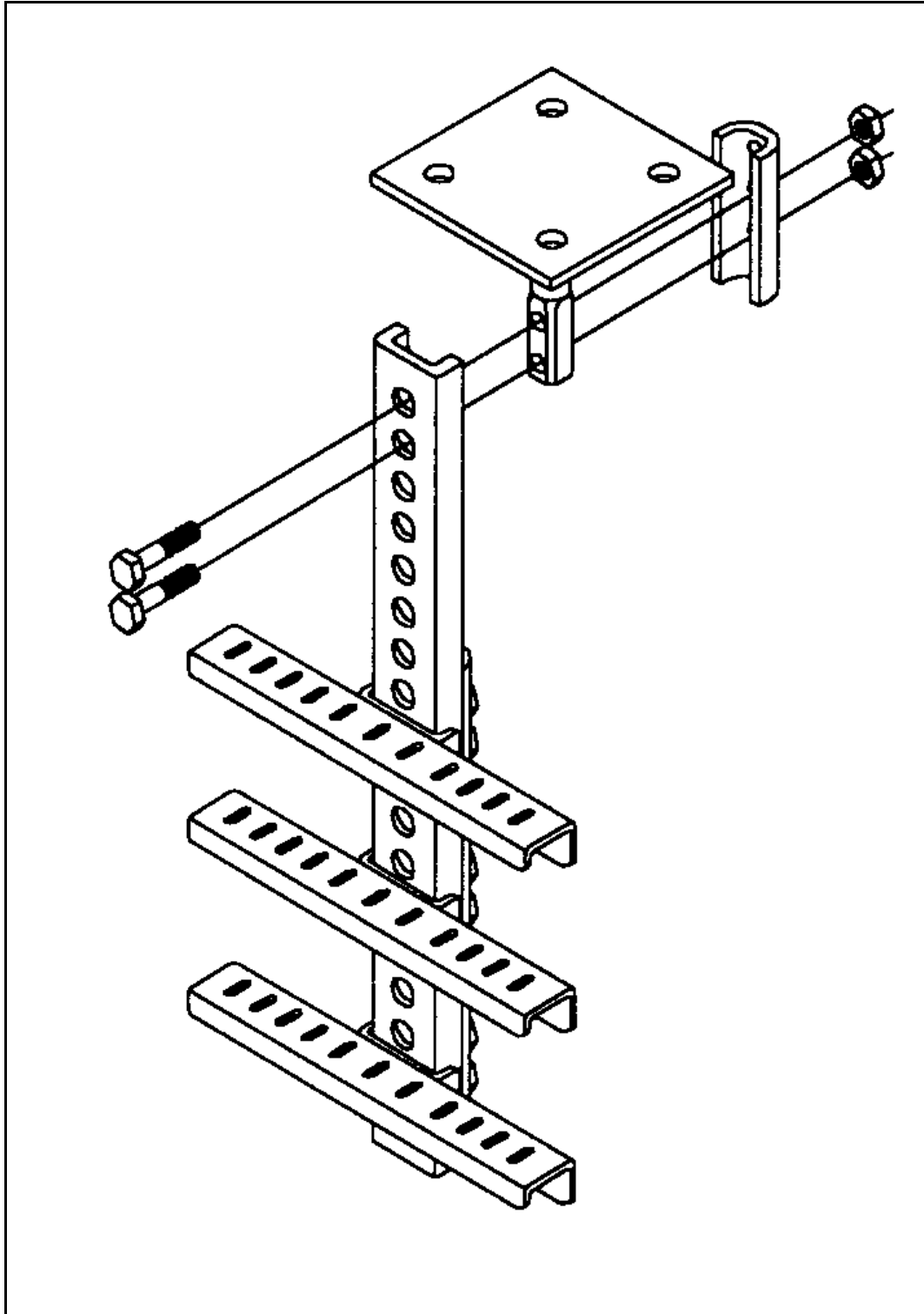
FOUNDATION ATTACHMENT DETAILS

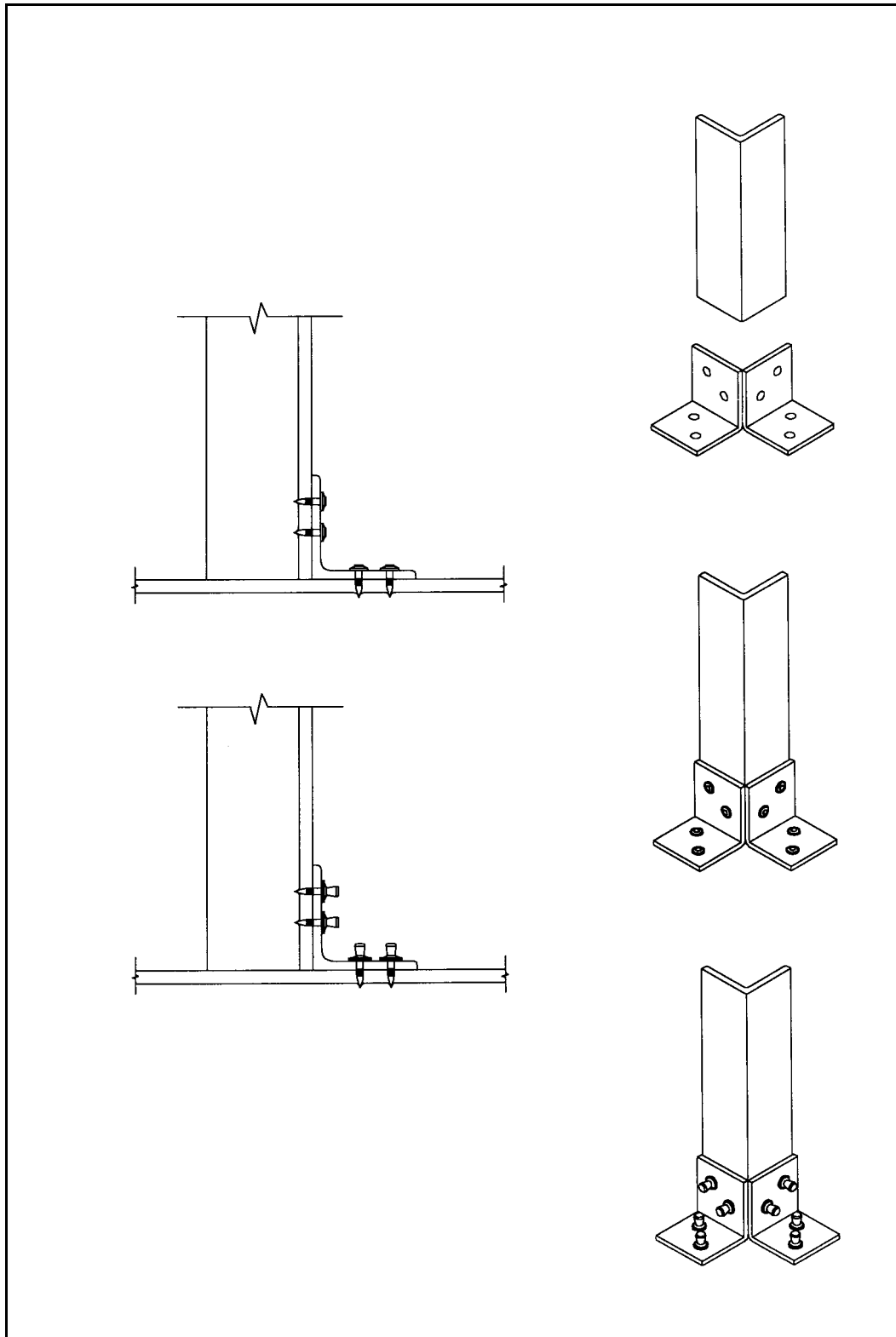


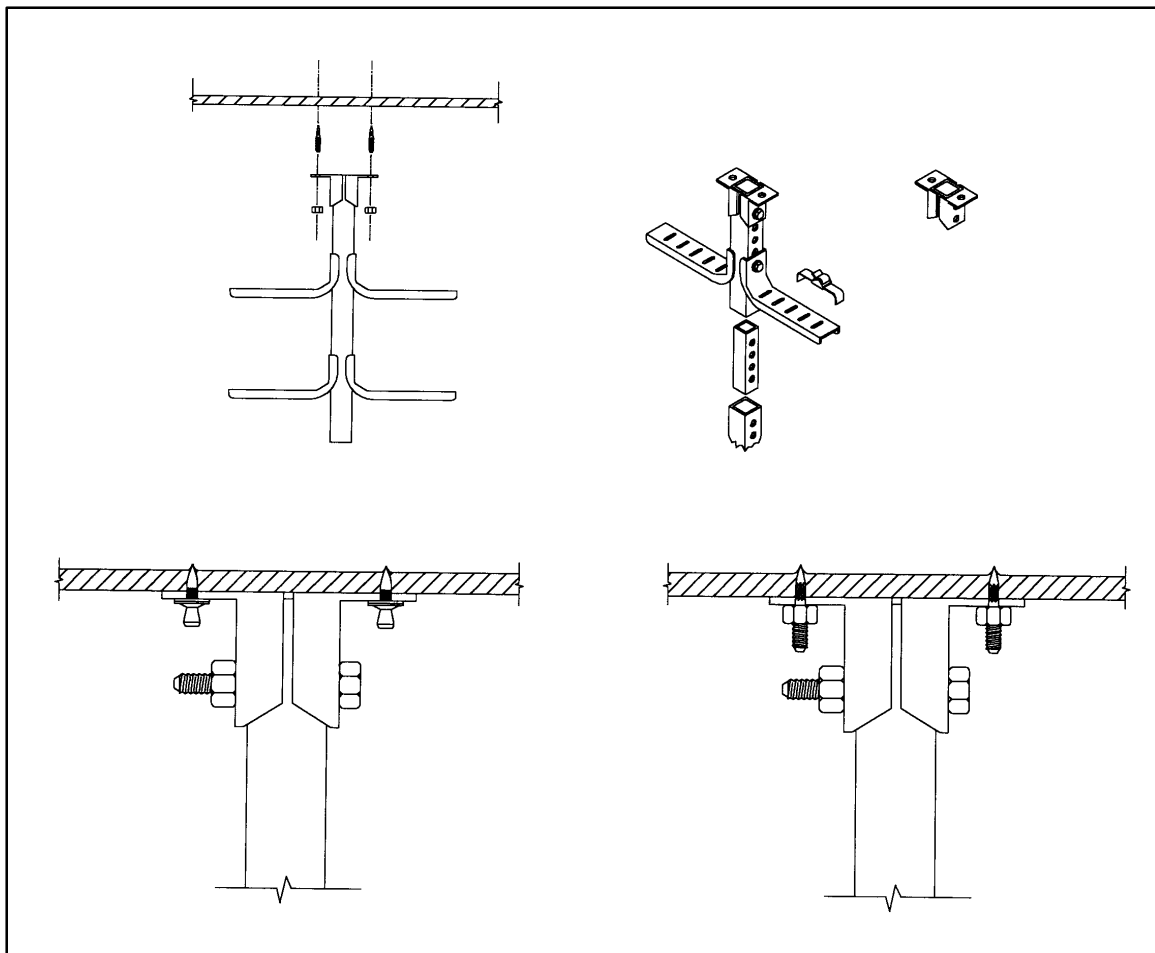


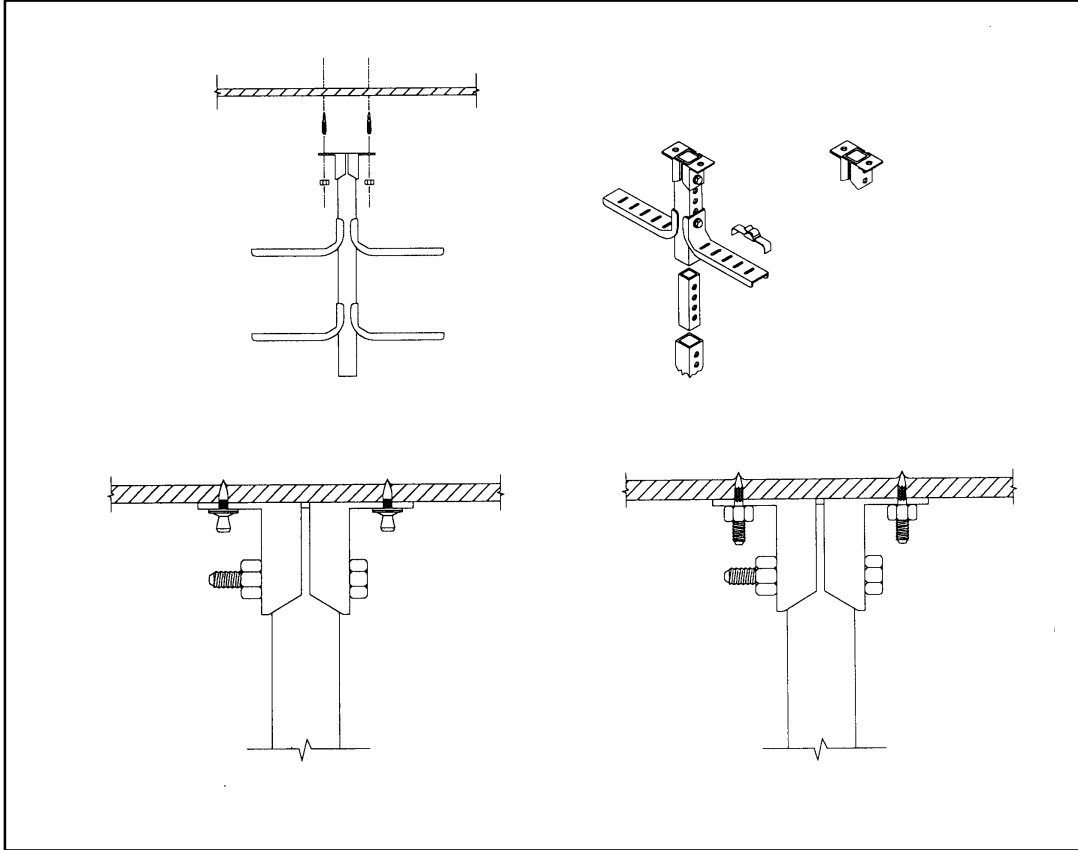
APPENDIX C — HILTI SYSTEM ATTACHMENT TECHNIQUES
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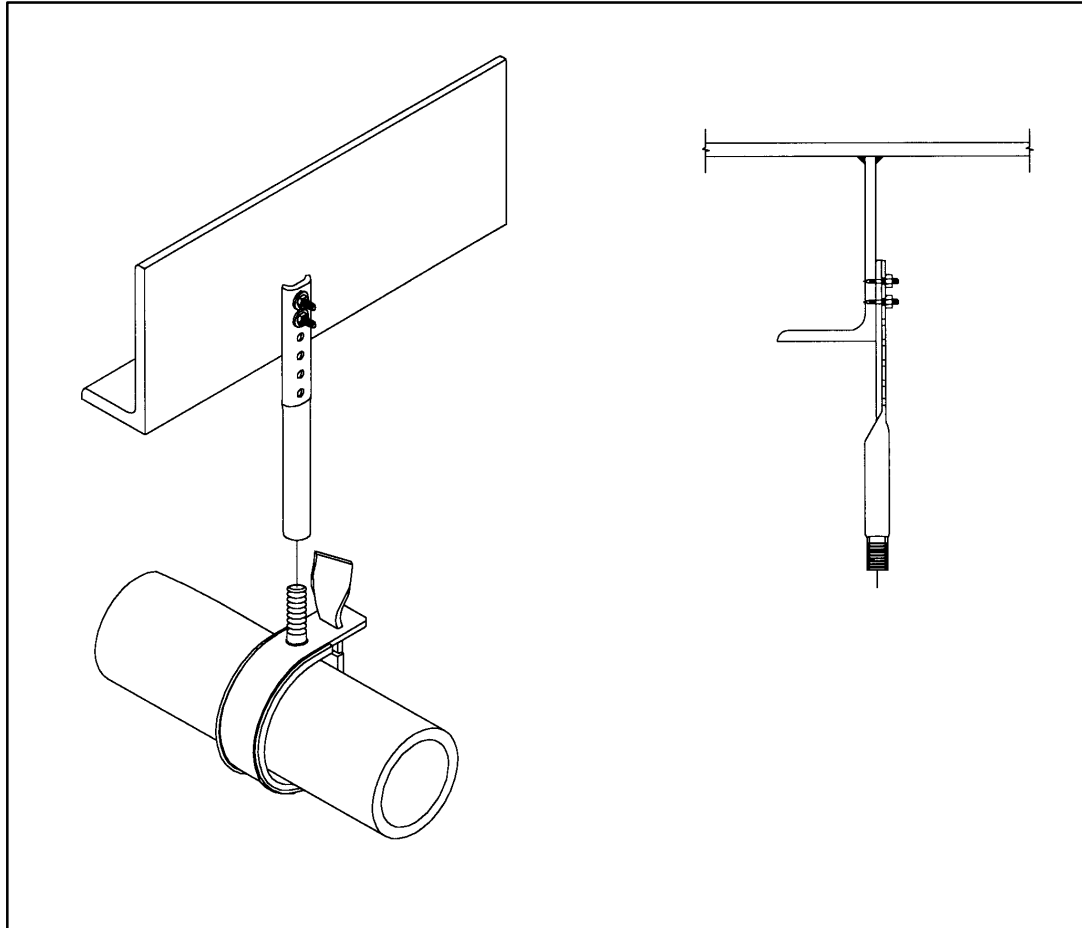


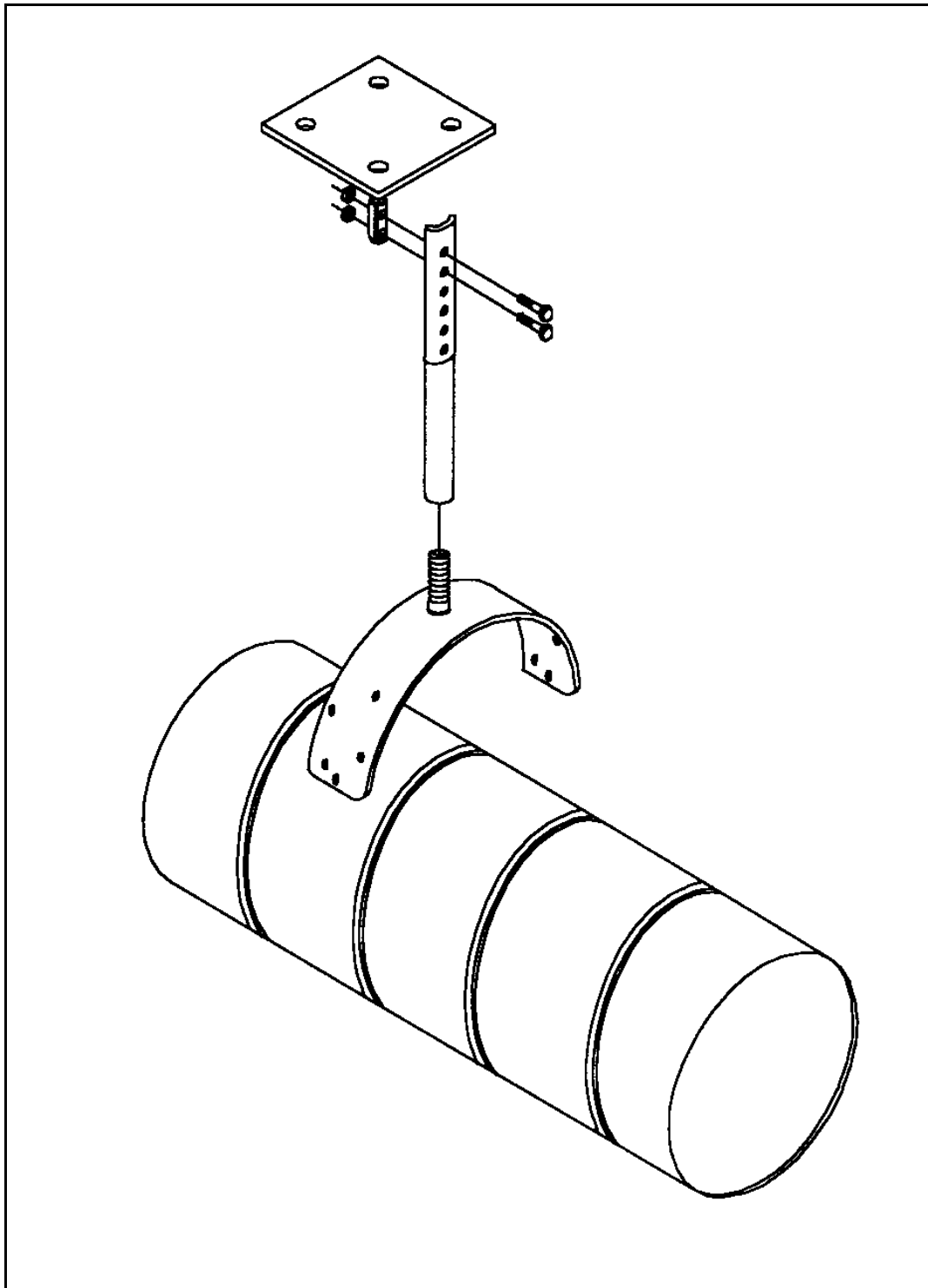






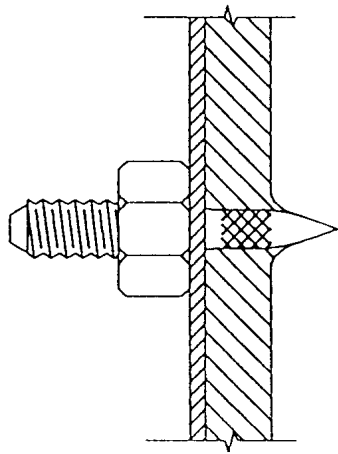




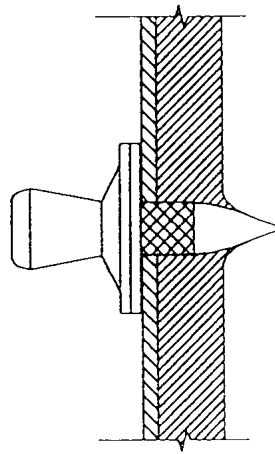


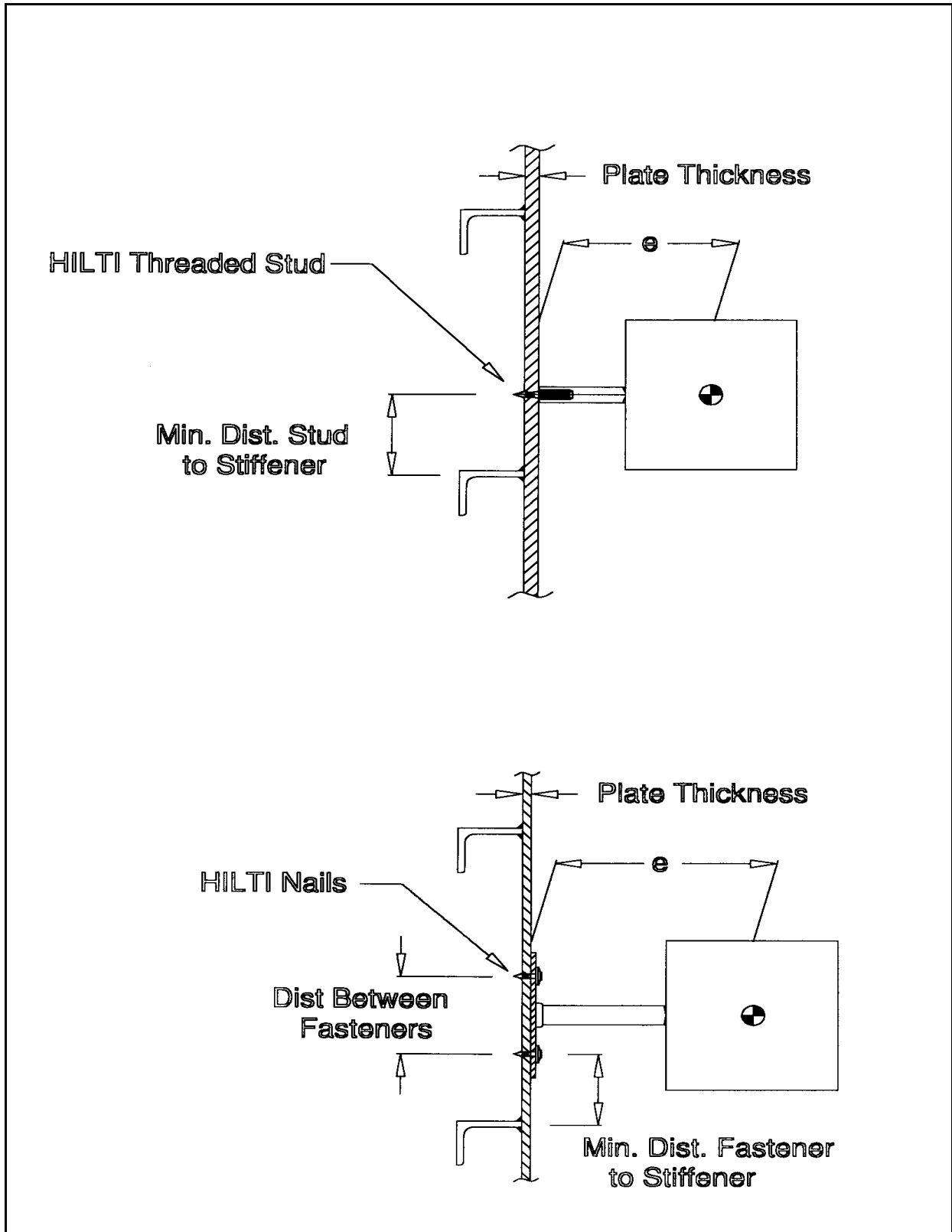
HILTI Fasteners

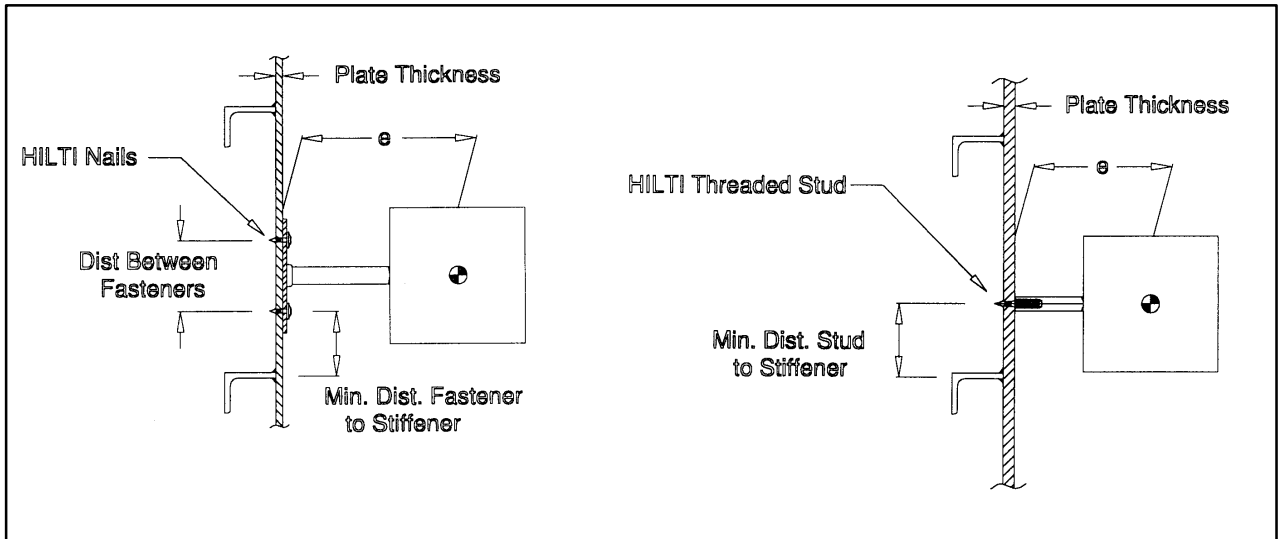
EW6H - Threaded Stud

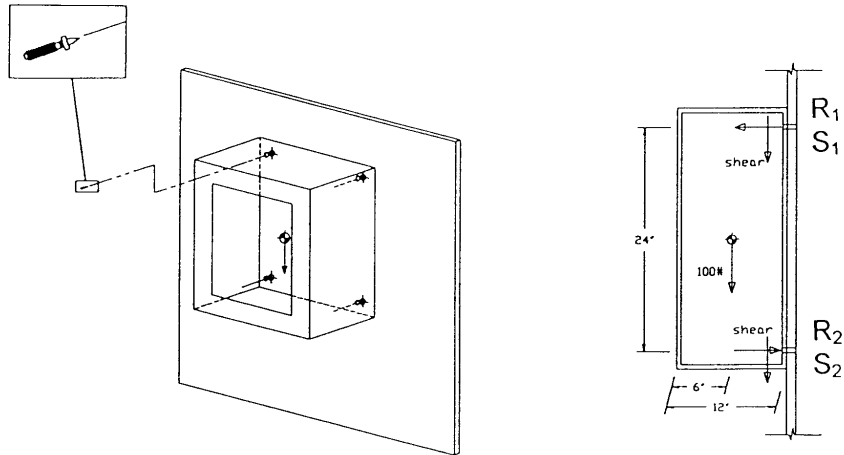


ENPH2 - High Strength Nail









Tension :

$$24" * R_1 = P * e$$

$$R_1 = (P * e) / 24"$$

$$R_1 = 100\# * 6" / 24"$$

$$R_1 = 25\#$$

Shear :

$$S_1 = S_2 = P / 4$$

$$S_1 = S_2 = 100\# / 4$$

$$S_1 = S_2 = 25\#$$

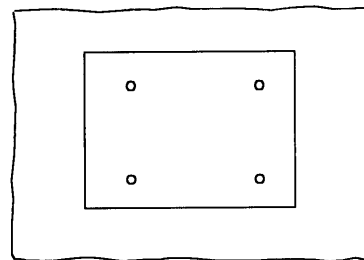
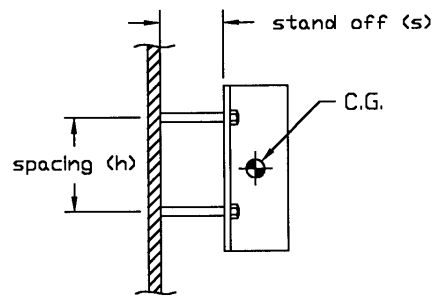
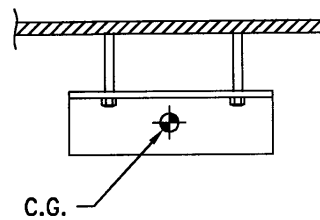
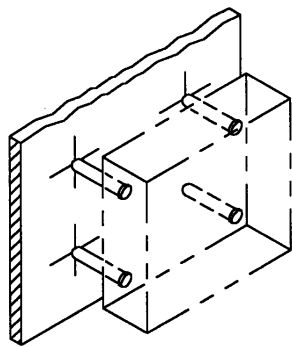
Allowable Loads - 3/8" Threaded Stud

	<u>Tension</u> (lbs.)	<u>Shear</u> (lbs.)
From Hilti Technical Data : (Using Safety Factor of 5:1)	1150	1540
Shipboard Use : (Using Safety Factor of 2:1)	2875	3850

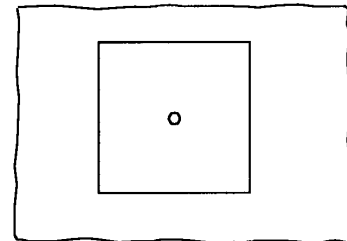
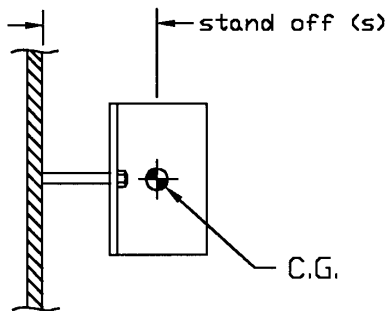
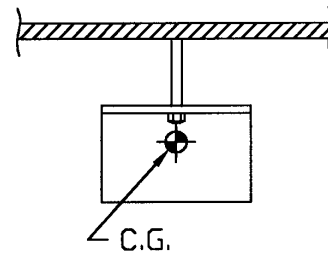
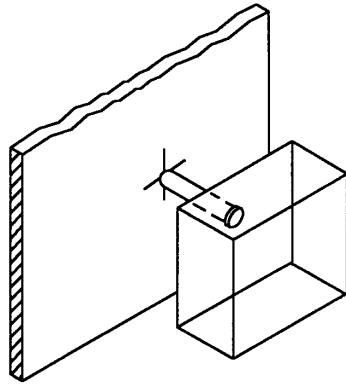
Load Factor : $2875 / 25 = 125$ $3850 / 25 = 154$

APPENDIX D — STUD MOUNTED ATTACHMENT TECHNIQUES
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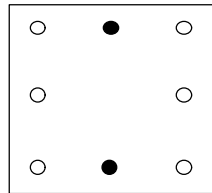
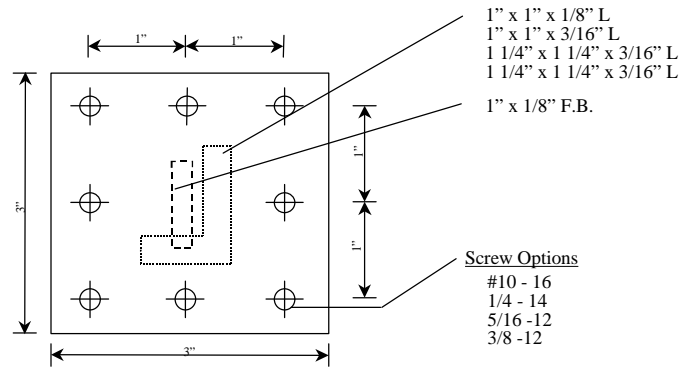
MUTIPLE STUDS



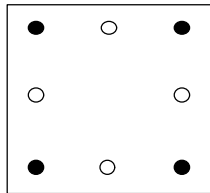
SINGLE STUD



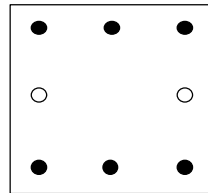
Fastener and Pad Configurations



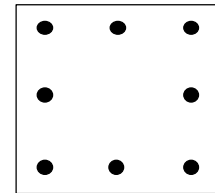
2 Fastners



4 Fastners



6 Fastners



8 Fastners

Note: Drawings not to scale.